ARAŞTIRMA / ORIGINAL ARTICLE

Gülhane Tıp Derg 2011; 53: 43-49

Evaluation of differences between two and three dimensional cephalometric measurements

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SUMMARY

The aim of this research was to compare the three dimensional (3D) craniofacial measurements with conventional two dimensional cephalometric measurements in patients with skeletal Class III malocclusion. The study was carried out on lateral cephalograms and axial computed tomography (CT) images of 44 patients. The 3D images were obtained and measured with Mimics 12.01 image processing software. Anatomic landmarks were first designated on the 3D surface model, and their positions were verified on sagittal, coronal, and axial planes. 14 angular and 18 linear measurements were performed on 3D images, and conventional cephalograms. After the evaluation of the results it was determined that the conventional two dimensional cephalometry and computer aided three dimensional cephalometry were close in depicting angular relations of structures, but they differed in the accuracy of linear measurements, except Nperp-A, Nperp-Pog, Overjet, Overbite, L1-NB, UL-E and LL-E.

Key words: *3D modeling, cephalometry, computed tomography, Mimics software program*

ÖZET

İki ve üç boyutlu sefalometrik ölçümler arasındaki farklılıkların değerlendirilmesi

Bu araştırmanın amacı, iskeletsel Sınıf III maloklüzyonu olan hastalarda üç boyutlu (3B) kraniyofasiyal ölçümleri, geleneksel iki boyutlu sefalometrik ölçümlerle karşılaştırmaktır. Çalışma 44 hastanın lateral sefalogramları ve aksiyel bilgisayarlı tomografi (BT) görüntüleri üzerinde yürütülmüştür. 3B görüntülerin oluşturulması ve ölçülmesi, Mimics 12.01 görüntü işleme yazılımı ile yapılmıştır. Anatomik yapılar önce 3B yüzey modeli üzerinde belirlenmiş ve pozisyonları sagital, koronal, ve aksiyal düzlemlerde doğrulanmıştır. 3B görüntüler ve geleneksel sefalometriler üzerinde 14 açısal ve 18 doğrusal ölçüm yapılmıştır. Sonuçların değerlendirilmesinde, yapıların açısal ilişkilerini tanımlamada geleneksel iki boyutlu sefalometri ve bilgisayar destekli üç boyutlu sefalometrinin birbirine yakın olduğu, ancak Nperp-A, Nperp-Pog, Overjet, Overbite, L1-NB, UL-E ve LL-E haricindeki doğrusal ölçümlerin farklılık gösterdiği tespit edilmiştir.

Anahtar kelimeler: *3D modelleme, sefalometri, bilgisayarlı tomografi, Mimics yazılım programı*

Introduction

Cephalometric radiographs have been used for diagnosis, treatment planning, and evaluation of treatment results in orthodontics (1-6). Not only the size and location of the maxilla and the mandible, but the relationship between the craniofacial structures can also be defined by the measurements made on these radiographs. Cephalometric analyses also show the soft tissue profile, and the positions and relations of the upper and lower incisors (3,4). Despite the advantages of low cost, low radiation dose, and high reproducibility, lateral cephalograms have several drawbacks especially in the evaluation of facial asymmetry and in the planning of orthognathic surgery (5-9).

In a conventional orthodontic treatment planning, the cephalometric analyses are used to measure values of skeletal, dental and soft tissue landmarks, and obtained values are compared with standard mean values to diagnose the problems of the patients (1,4,6). However, ideal skeletal, dental, and soft tissue relationship can differ according to the cephalometric analysis method used. There is a wide database regarding radiographic cephalometry since this technique has been used for long years in orthodontics. Values of clinically normal patients are calculated and aberrations are determined angularly, linearly, or proportionally by using these databases so, cephalometric evaluation still maintains its indispensable way in the orthodontic treatment planning (6).

Recently, new software programs have been developed to enable the analysis of data which are obtained by three dimensional (3D) visualisation techniques (1,2,4). Evaluation and measurement of craniofacial structures by 3D cephalometric analyses, developing orthodontic treatment planning, post-treatment soft tissue simulations, and real 3D solid biomodelling have been possible by these techniques (10-15). By using computed tomography (CT) images without magnification, distortion, and superposition, 3D

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Date submitted: October 22, 2010 • **Date accepted:** December 23, 2010

reconstruction, segmentation, and simulation can be done by means of computer programs (2,4,11). However, there are no available standard norm values regarding 3D images since it is a new developing technique (16). Although different 3D analysis methods have been recommended, interpreting a measurement or even more developing a treatment plan according to these analyses is rather difficult since the exact standard values are still unknown (7,17).

While developing a new method that can be used on 3D images the answers of the following questions are important: Can conventional cephalometry measurements be carried out on 3D images? Are the norm values used in conventional cephalometry in accordance with 3D cephalometry? Can orthodontic treatment planning be done on 3D images with merely the conventional cephalometric analyses made on lateral cephalograms? When the answers of these questions are found out, 3D cephalometry would be more accurately and frequently used in orthodontics.

In the present study, it was aimed to compare the three dimensional (3D) craniofacial measurements with conventional two dimensional cephalometric measurements in patients with skeletal Class III malocclusion. The principal goal was to search if conventional cephalometry could be used on 3D images of the facial structures.

Material and Methods

In this retrospective study, pretreatment lateral cephalometric radiographs and CT images of 44 patients with skeletal Class III (ANB<0°) malocclusion were used. Thirty one of the selected patients were male with a mean age of 21.6 years, and 13 of them were females with a mean age of 20.4 years.

Lateral cephalometric radiographs were taken with Odontorama P.C. radiography instrument (Trophy Radiologie, France) by using 18x24 cm sized x-ray films. The distance between patient and x-ray source was 150 cm, while it was 12 cm between the film cartridge and the patient. These values were standard for all radiographs. Computed tomography images were obtained by using Philips MX 8000 IDT Multislice CT System V 2.5 (Philips Medical Systems, The Netherlands) instrument, at a dose of 120 kV and 100 mA, with a section thickness of 1 mm. These images were registered to compact disc environment in DICOM format. While conventional cephalometric measurements were performed by tracing the radiographs with a 0.3 mm pencil, 3D cephalometric analyses were made by converting tomography data to 3D via Mimics® v12.01 (Materialise, Leuven, Belgium) software.

In 3D images, segmentation of soft tissue, vertebra, mandible, and cranium were done separately so as to mark the cephalometric points more easily. Cephalometric analysis program of Mimics® simulation module was used for cephalometric measurements. After the anatomic points were marked on 3D model and controlled via sagittal, coronal and axial reformat sections (Figure 1), the program gave the results of cephalometric analysis in two different numerical value forms as 3D and 2D (Figure 2). The average values of the measurements belonging to the right and left structures were used.

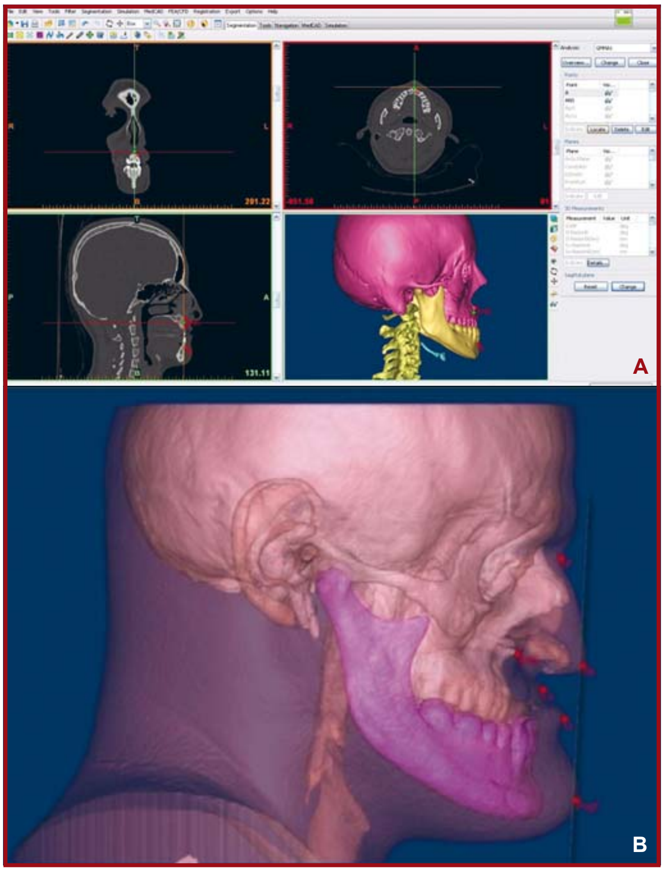

Figure 1. A,B. Marking cephalometric points on Mimics® program

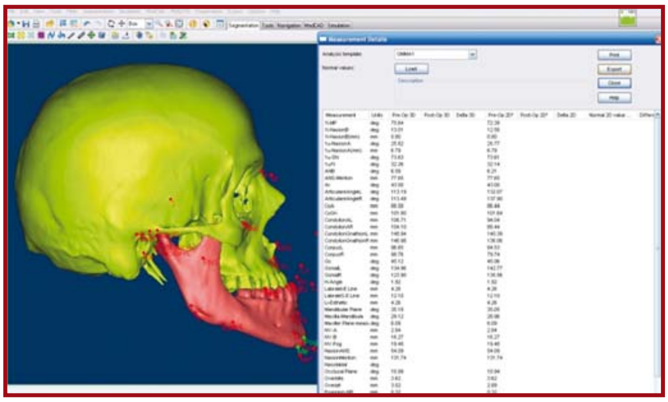

Figure 2. Cephalometric analysis results on Mimics® program

Table I. Landmarks used in the study

Landmark	*Abbreviation*	*Description*
1. Nasion	N	The most anterior point of the nasofrontal suture on midsagittal plane
2. Sella	S	The center of the hypophyseal fossa (sella turcica)
3. Orbitale	Or	The lowest point on the lower magrin of each orbit
4. Porion	Po	The upper magrin of the porus acusticus externus
5. Anterior nasal spine	ANS	The most anterior point of the maxilla on midsagittal plane
6. Posterior nasal spine	PNS	The most posterior point at the sagittal plane on the bony hard palate
7. Point A	A	Deepest point on midsagittal plane between ANS and prosthion
8. Point B	B	The deepest midline point on the mandible between infradentale and pogonion
9. Pogonion	Pog	The most anterior pointon the mandible in the mildine
10. Menton	Me	Most inferior point on the symphysis of the mandible in the median plane
11. Gnathion	Gn	The most anterior-inferior point of the bony chin
12. Gonion	Go	A posterio-inferior point on the ramus
13. Condylion	Co	The most posterior superior point on the condyle of the mandible
14. Incision superius	Is1u	Tip of incisal edge of anteriormost upper incisor
15. Upper incisor apex	Ap1u	The root apex of the most prominent upper incisor
16. Incision inferius	Is1l	Tip of incisal edge of anteriormost lower incisor
17. Lower incisor apex	Ap1l	The root apex of the most prominent lower incisor
18. Occlusal 1	Occ1	Upper and lower first molar occlusal contact point
19. Occlusal 2	Occ2	Overbite midpoint
20.Labrale superius	Ls	The most anterior point on the magrin of the upper membranous lip
21. Labrale inferius	Li	The most anterior point on the magrin of the lower membranous lip
22. Pronasale	Ns	The most anterior point on the midsagittal profile of the nose
23. Soft tissue pogonion	Pog’	The most anterior point on the soft tissue chin in the midsagittal plane
24. Soft tissue nasion	N’	The deepest point on the concavity overlying the area of the frontonasal suture

In this study, 24 cephalometric points were used (Table I and Figure 3). The selection of the points was made by considering the frequency of the usage in orthodontics. The points of intersection or superposition were not selected since they were hardly detected on 3D images. 14 angular (Figure 4) and 18 linear (Figure 5) measurements were performed by conventional method, MIMICS 3D, and MIMICS 2D

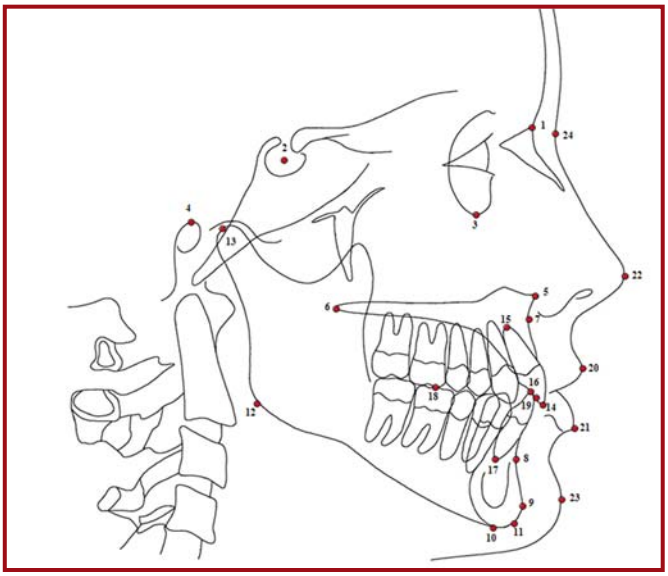

Figure 3. Determined anatomic landmarks

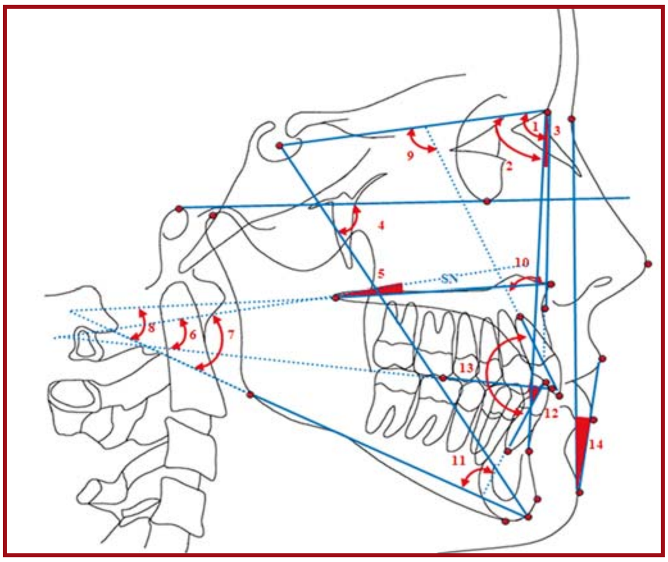

Figure 4. Selected angular measurements 1.SNA, 2.SNB, 3.ANB, 4.Y-Axis, 5.SN/ANS-PNS, 6.SN/Occ, 7.SN/Go-Gn, 8.ANS-PNS/Go-Gn, 9.U1/SN, 10.U1/NA, 11.L1/Go-Gn, 12.L1/NB, 13.U1/L1, 14.H-Angle

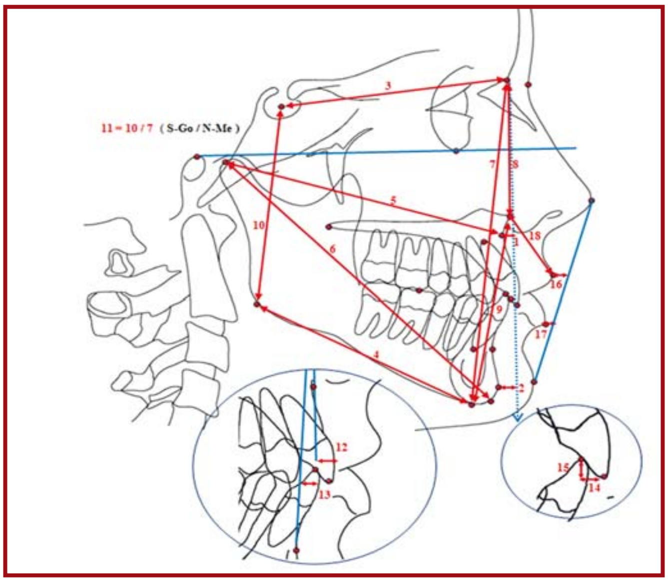

Figure 5. Selected linear measurements 1.NPerp-A, 2.NPerp-Pog, 3.S-N, 4.Go-Me, 5.Co-A, 6.Co-Gn, 7.N-Me, 8.N-ANS, 9.ANS-Me, 10.S-Go, 11.S-Go/N-Me, 12.U1-NA, 13.L1-NB, 14.Overjet, 15.Overbite, 16.UL-E(Ls to E- Line), 17.LL-E(Li to E-Line), 18.UL-Lenght(ANS-Ls)

and the results were categorized as Group I, Group II, and Group III, respectively (Table II).

Measurements carried out in three different ways were evaluated by applying repeated measures analysis of variance. In order to determine probable differences among 3 experimental groups compared, Wilks' Lambda statistical analysis method was used. When a difference was observed, Bonferroni post-hoc test was used in order to detect the source of difference. In the evaluation of the parameters which were not in accordance with normal distribution, Friedman non-parametric repetitive measurement analysis was applied. When difference was observed between the groups, Bonferroni corrected Wilcoxon non-parametric two dependent sample test was used to determine the differences. For all statistical analyses and calculations, MS-Excel and SPSS for Win. Ver. 15.00 (SPSS Inc. Chicago, IL., USA) packaged software were used. The significance level was set at $p< 0.05$.

Results

Evaluation of the angular measurements revealed statistically significant differences in SNA ($p<0.001$), SNB ($p=0.10$), ANB ($p=0.001$), ANS-PNS/Go-Gn ($p=0.023$) and U1/L1 ($p=0.046$) values between Group I and Group II and all of the parameters were higher in Group II. Comparison of Group I with Group III showed statistically significant differences in SNA ($p<0.001$), SNB ($p=0.07$), ANB ($p=0.004$), L1/Go-Gn ($p=0.018$) and U1/L1 ($p=0.021$). All of the parameters, except L1/Go-Gn, were higher in Group III. Y-Axis ($p=0.012$), SN/Occ ($p<0.001$), SN/Go-Gn ($p=0.002$), ANS-PNS/Go-Gn ($p=0.001$), U1/SN ($p=0.016$), U1/NA ($p=0.001$), L1/NB ($p=0.020$) and H-Angle ($p=0.005$) revealed statistically significant differences in the comparison of Group II and Group III. All of the parameters, except U1/SN, were higher in Group II (Table II).

In the examination of the linear measurements, significant differences were detected in S-N ($p<0.001$), Go-Me ($p<0.001$), Co-A ($p<0.001$), Co-Gn ($p=0.003$), N-Me ($p<0.001$), N-ANS ($p<0.001$), ANS-Me ($p<0.001$), S-Go ($p<0.001$), U1-NA ($p<0.001$), L1-NB ($p=0.004$), LL-E ($p=0.028$), UL-Length ($p<0.001$) and S-Go/N-Me ratio ($p<0.001$) between Group I and Group II. All of the linear measurements, except Go-Me, Co-A, S-Go and S-Go/N-Me, were higher in Group I according to Group II. The comparison of Group I and Group III revealed significant differences in S-N ($p<0.001$), Go-Me ($p<0.001$), Co-A ($p<0.001$), Co-Gn ($p<0.001$), N-Me ($p<0.001$), N-ANS ($p<0.001$), ANS-Me ($p<0.001$), S-Go ($p<0.001$), U1-NA ($p<0.001$), L1-NB ($p<0.001$), LL-E ($p=0.031$), UL-Length ($p<0.001$). All of the linear measurement values in Group I were higher than the values in Group III. In the comparison of Group II and Group III, NPerp-A ($p=0.011$), NPerp-Pog ($p=0.005$), S-N ($p<0.001$), Go-Me ($p<0.001$), Co-A ($p<0.001$), Co-Gn ($p<0.001$), N-ANS ($p<0.001$), S-Go ($p<0.001$), S-Go/N-Me ($p<0.001$), U1-NA ($p<0.001$), L1-NB ($p<0.001$), Overjet ($p<0.001$), UL-E ($p<0.001$), LL-E ($p=0.001$), UL-Length ($p=0.005$) showed statistically significant differences. All linear measurement values, in Group II were greater than the values in Group III. In other words, the findings of our study revealed that the linear measurements showed the highest values in Mimics 3D cephalometry and the lowest values in Mimics 2D cephalometry.

Discussion

Cephalometric analyses have been frequently used as the primary diagnosis tool in orthodontics for the assessment of craniofacial structures. However, despite their advantages such as low cost, low radiation dose, and high reproducibility, they still have some shortcomings because of the superimposition of structures of the left and right side of the skull, the unequal enlargement ratios of the left and right side, and the possible distortion of the mid-facial structures (18,19). Recently, 3D cephalometry obtained from CT scans has been developed as an alternative to cephalometric analysis. In this technique, the linear and angular measurements are made directly on 3D surfaces (16,20).

In the first studies, cranium was monitorized with CT and only axial section data was examined without applying 3D reconstruction and the researchers eva-

Table II. Mean and standard deviation values, inter-group distributions of repeated measurements analysis of variance and Bonferroni post-hoc test

	Group I (Conventional) mean ± std dev.	*Group II (MIMICS 3D) mean ± std dev.*	*Group III (MIMICS 2D) mean ± std dev.*	*test*	*I-II*	*I-III*	*II-III*
Skeletal							
Skeletal angular							
SNA	78.455±4.043	79.626±4.186	79.625±4.173	***	***	***	ns
SNB	83.705±5.165	84.455±5.331	84.490±5.335	**	*	**	ns
ANB	-5.250±3.498	-4.830±3.499	-4.865±3.471	*	**	**	ns
Y-Aksis	57.750±5.248	57.685±5.838	57.562±5.772	**	ns	ns	*
SN/ANS-PNS	9.068±4.049	8.616±4.345	8.603±4.340	*	ns	ns	ns
SN/Occ	14.955±6.548	16.346±9.020	15.929±9.124	**	ns	ns	***
SN/Go-Gn	34.455±7.125	34.371±7.124	34.160±7.266	**	ns	ns	**
ANS-PNS/Go-Gn	25.205±6.465	25.959±6.778	25.680±6.889	***	*	ns	**
Skeletal linear							
NPerp-A	-3.364±3.314	-3.038±3.201	-3.033±3.196	**	ns	ns	*
NPerp-Pog	8.205±8.733	9.310±8.744	9.294±8.729	**	ns	ns	*
SN	74.386±4.701	67.242±4.079	67.098±4.027	***	***	***	***
Go-Me	83.545± 6.407	89.575±5.820	75.281±6.003	***	***	***	***
Co-A	90.636±7.038	98.080±6.358	83.420±6.083	***	***	***	***
Co-Gn	138.409±10.228	136.330±8.022	126.153±7.945	***	**	***	***
N-Me	138.795±11.099	126.047±9.893	125.949±9.838	***	***	***	ns
N-ANS	59.386±4.794	53.637±4.201	53.596±4.220	***	***	***	***
ANS-Me	79.955±8.441	72.944±7.633	72.788±7.609	***	***	***	ns
S-Go	89.386±8.269	93.613±6.992	80.060±7.082	***	***	***	***
S-Go/ N-Me	0.646±0.054	0.745±0.049	0.637±0.050	***	***	ns	***
Dental							
Dental angular							
U1/SN	106.614±7.851	106.349±7.851	106.391±7.851	*	ns	ns	*
U1/NA	27.364±6.567	26.854±6.681	26.745±6.676	**	ns	ns	**
L1/Go-Gn	78.227±7.554	78.540±6.761	76.247±8.112	***	ns	*	***
L1/NB	15.841±6.038	15.416±6.529	15.032±6.773	*	ns	ns	*
U1/L1	140.977±10.936	142.888±11.867	143.108±12.100	*	*	*	ns
Dental linear							
U1-NA	5.977±2.445	3.693±2.253	2.179±2.353	***	***	***	***
L1-NB	3.080±2.023	2.345±2.290	1.186±1.521	***	**	***	***
Overjet	-4.261±3.918	-4.005±3.657	-3.898±3.586	**	ns	ns	***
Overbite	0.045±3.906	0.252±4.354	0.252±4.347	ns	ns	ns	ns
Soft tissue							
Soft tissue angular							
H-Angle (N'Pog'Ls)	3.159±5.048	3.158±5.296	2.773±4.737	*	ns	ns	**
Soft tissue linear							
UL-E (Ls-E Line)	-10.182±3.105	-10.273±2.668	-10.253±2.663	***	ns	ns	***
LL-E (Li-E Line)	-3.409±3.029	-3.853±2.716	-3.846±2.713	***	*	*	**
UL-Length (ANS-Ls)	25.727±3.216	21.956±2.837	21.709±3.047	***	***	***	**

*p<0.05, **p<0.01, ***p<0.001, ns: non significant

luated these images with a physical anthropological point of view without considering the orthodontic points (21,22). In some previous studies, cephalometric radiographs and CT images were compared with physical measurements, and the results revealed some important differences between conventional cephalometric measurements and physical measurements of cranium (5,23), whereas the measurements of 3D CT images were closer to physical measurements (24-26). Lopes et al. used 28 dry skulls and 3D CT images to examine the accuracy and sensitivity of angular measurements and stated that there was no difference between the two groups (16). Similarly, Chidiac et al. used 13 skulls to compare the conventional cephalometric measurements and the measurements carried out on CT images with each other and with physical measurements (25). The authors reported significant differences at linear measurement values between conventional cephalometry and CT images. Nevertheless, there were no differences at angular measurements.

Togashi et al. investigated whether the position of the head affected the accuracy of the linear measurements performed on 3D CT images (20). The investigators obtained CT images of the cranium with thicknesses of 1 mm, 3 mm, 5 mm, and 7 mm at different head positions. They concluded that the measurements made on 3D CT images were independent from the head position but the increase in the section thickness might cause failures in some linear measurements. Similarly, Kitaura et al. (7), Cavalcanti et al. (24), and Park et al. (15) showed that the axial section thicknesses of CT images affected the quality of 3D images. Kitaura et al reported that, the 3D images obtained with section thickness less than 3 mm were almost without failure when compared to actual values (7). On the other hand, it was reported that, in contrast to CT images, the inappropriate head position affected the accuracy of the linear and angular measurements made on lateral cephalograms (27,28).

In the light of these findings, the CT images were obtained with an axial section thickness of 1 mm in our study. Although some authors reported that the head position did not affect the CT images (7,20), we obtained the CT images with Gantry and Tilt values of 0° (Frankfurt Horizontal plane was perpendicular to ground plane without head rotation), taking into consideration the suggestions of the computer program that was used in our study.

Lateral cephalograms are 2D projection images of 3D objects. For this reason, anatomic structures are usually subjected to either vertical or horizontal displacement depending on the distance between the objects and the radiograph. It is notified that, magnification is observed in most of the craniofacial structures, with rates varying from approximately 0% in structures at the side close to the film and on central ray, and to 24% in structures which are 60 mm or more far from ear sticks (5-9). Because of that, the use of a constant magnification correction for every measurement value carried out on 2D conventional cephalograms could lead to some mistakes. The results of our study revealed that the differences in the magnifications observed in 2D conventional cephalograms and 3D images were statistically significant in linear measurements. The differences were varying between 1.52% and 38.21% and no constant rate was observed. In the light of this finding, it can be concluded that a standard magnification correction for every measurement could create inaccurate results.

The Gonion (Go) and Condilion (Co) points are far from mid-sagittal plane and belong to bilateral structures. Kragskov et al. who compared the conventional 2D cephalometric measurements and the measurements applied on 3D CT images stated that in oblique measurements of bilateral structures and points on the mid-sagittal plane, the results of conventional cephalometry values were lower than physical and 3D measurement values (29). The magnification in conventional cephalograms, made the values of Go-Me, Co-A and S-Go closer to the 3D measurement. However, the values of Group I were still lower than those of Group II in our study. Although it has the same characteristics, Co-Gn measurement was higher in conventional cephalometry (Group I), when compared to the 3D cephalometric measurements (Group II). Gnathion (Gn) point is one of the furthest points from the central ray, and this may be the reason of the higher magnification observed in the conventional cephalometry. These findings are in accordance with the findings of Adams et al (5) and Kragskov et al (29).

Kumar et al. compared the images obtained via Cone Beam CT with conventional cephalograms and stated that the differences of ± 2 degrees between angular measurements and of ±2 mm between linear measurements were clinically insignificant (30). Cavalcanti et al. (24), Periago et al. (31), and Jamali et al. (32) also reported similar results. In our study, the differences between the groups were lower than 2 degrees in the angular measurements. Additionally, it was lower than 2 mm in the linear measurements of Nperp-A, Nperp-Pog, Overjet, Overbite, L1-NB, UL-E and LL-E. In the light of findings reported by the above authors, it can be stated that although some of these parameters were statistically significant; these small differences may be clinically ignored.

In the light of our findings the followings can be concluded: 3D visualization is an ideal visualization technique for orthodontics since it enables more sensitive measurement and planning. In conventional cephalometry, and computer aided 3D and 2D cephalometry, the angular measurements were consistent with each other. In linear measurements, except the measurement values of of Nperp-A, Nperp-Pog, Overjet, Overbite, L1-NB, UL-E and LL-E, significant differences were observed. No current norm values are available for 3D cephalometry. Until a database is developed for 3D cephalometry, the conventional cephalometric norms may be used for the angular measurements. In conventional cephalometry, standard magnification correction for every measurement may create inaccurate results.

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