A Comparison of Three-Dimensional and Two-Dimensional Cephalometric Evaluations of Children with Cleft Lip and Palate

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ABSTRACT

Objectives: The aim of this retrospective study was to compare the consistency of orthodontic measurement performed on cephalometric films and 3D CT images of cleft lip and palate (CLP) patients.

Methods: The study was conducted with 2D radiographs and 3D CT images of 9 boys and 6 girls aged 7-12 with CLP. 3D reconstructions were performed using MIMICS software.

Results: Frontal analysis found statistical differences for all parameters except occlusal plane tilt (OcP-tilt) and McNamara analysis found statistical differences in 2D and 3D measurements for all parameters except ANS-Me and Co-Gn; Steiner analysis found statistical differences for all parameters except SND, SNB and Max1-SN. Intra-group variability in measurements was also very low for all parameters for both 2D and 3D images.

Conclusions: Study results indicate significant differences between measurements taken from 2D and 3D images in patients with cleft lip and palate. (Eur J Dent 2011;5:451-458)

Key words: 3D reconstruction; Computerized tomography; Cephalometry; CLP.

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INTRODUCTION

Conventional cephalometry is an inexpensive and essential method for evaluating orthodontic patients.[1,2] However, it is difficult to evaluate patients with major craniofacial deformities, in particular facial asymmetry, using conventional cephalometry.[1] For this reason, three-dimensional computed tomography (3D-CT) imaging is widely used in the diagnosis and surgical treatment planning of patients with craniofacial deformities.[3-5] 3D-CT data is especially helpful in evaluating pa-

tients with asymmetry because they do not suffer from the magnification- and distortion-related problems inherent in 2D projections.

With the general trend away from traditional 2D cephalometric analysis towards new 3D techniques, it is helpful to compare the use of different applications in various settings.[6,7] A study conducted by Kragskov et al[1] comparing lateral and frontal cephalograms and CT scans of human dry skulls found lateral cephalograms to be more reliable than 3D-CT, with less than 1 mm of variation between observers for most points, compared to about 2 mm for 3D-CT images. Differences between 3D-CT and frontal cephalograms were less obvious. They also stated that, frontal cephalometrics showed significantly less inter-observer variation, and for standard lateral and frontal cephalometric points, there is no evidence that 3D-CT is more reliable than the conventional cephalometric methods in normal skull.[1] However, conventional cephalometrics are inadequate for assessing patients with severe asymmetric craniofacial syndromes; therefore, 3D-CT cephalometrics are indicated in such patients.[1,8]

Adams et al[8] found 3D evaluation to be more precise than 2D evaluation. Their results indicate that, when the actual distance is measured on a human skull in its true dimensions of 3D space, is more precise and 4 to 5 times more accurate than the 2D approach.[8] Various authors have stated that in patients with clefts, 3D imaging provides a better understanding of bone and soft-tissue defects than 2D imaging.[1,8-10]

Most patients requiring routine orthodontic treatment do not require successive CT scans. However, predicting growth is very important in patients with severe soft and bony tissue defects, especially in cases where repeated surgical intervention or reconstruction is envisaged.[11] In such cases, patients needed to be followed closely so that surgeons can track the changes that occur between examinations in order to ensure accurate planning and successful intervention.[12,13]

The MIMICS 10.02 (Materialise, Belgium) software program has advanced features that perform 3D reconstruction of CT data as well as most types of anthropometric analysis. There are several studies on patients with severe craniofacial defects using software allowing 3D reconstruction of CT scan data and anthropometric analyses, reporting conflicting findings on the advantages and disadvantages of the usage of software versus cephalometric analyses performed on conventional two dimensional lateral cephalography.[1,5,8,13,14]

This retrospective study aimed to compare Mc-Namara, Steiner and Frontal analyses performed using conventional 2D lateral and frontal cephalometric radiograms and 3D CT images in a population of children aged 7-12 years with cleft lip and palate.

MATERIALS AND METHODS

Study participants were selected from among the 118 patients treated for CLP at the Medical Faculty's Department of Reconstructive and Plastic Surgery between 2005-2009. Of these, 21 patients had lateral and frontal cephalometric films and 3D CT images in the department archives; however, 6 patients were excluded because of the time lapse (3-6 months) between when the cephalograms and 3D CT images were obtained. In total, orthodontic analysis was performed using radiograms and cranial CT images of 15 children with CLP (9 boys, 6 girls; age range: 7-12 years).

CT scans (Discovery, General Electric's, USA) were obtained using a strict, standardized protocol, with the patient in a horizontal position and the patient's head positioned with the help of a head positioner. Three-dimensional reconstruction and orthodontic measurement were performed using the MIMICS software program (MIMICS 10.02, Materialise, Belgium).

Standard lateral and frontal cephalograms were taken at the same magnification with the same equipment using a cephalostat incorporated into a conventional x-ray device (Proline 2002, Planmeca OY, Finland). Cephalometric films were traced using a protractor with an accuracy of 0.5 mm and 0.5°. All landmark identification and analysis was performed by the same orthodontist, and measurements were repeated after 15 days to control for examiner error. For some symmetrical parameters (Co-Gn, Co-A, SN-Go-Gn, SpPo-GoMe) mean values of left- and right-side measurements from 3D images were calculated in order to compare 2D and 3D measurements. McNamara, Steiner and Frontal analyses landmarks included in Mimics software program were measured. Measurements included both vertical and antero-posterior components of the craniofacial form.

Statistical analysis

All statistical analysis was carried out using the statistical software package SPSS version 11.5 (SPSS Inc., Ill, USA). Mann Whitney U tests was performed to identify differences between the 2D and 3D groups, with a level of significant set at P<.05. Intra-class correlation (ICC) coefficients were calculated to determine the reliability of measurements.

RESULTS

ICC coefficients were very high for both 2D (0.94-0.99) and 3D measurements (0.88-0.99). Results of Frontal, McNamara and Steiner analyses are given, respectively, in Tables 1, 2 and 3. Frontal analysis found all parameters except for OcP-tilt to be significantly higher in the 2D group when compared to the 3D group. McNamara analysis found no differences between ANS-Me and Co-Gn measurements in the 2D and 3D groups; however, Co-A was significantly higher (P<.01) and Maxillo-Mandibular difference (max-mand) and SpPo-GoMe were significantly lower (P<.05 and P<.001, respectively) in the 3D group when compared to the 2D group. Steiner analysis found no significant differences between 2D and 3D groups for the parameters SNB, SND and Max1-SN; however, ANB, Mand1-NB, Max1-NA, SNGoGN and SNA were significantly greater and interincisal angle (1-1) significantly smaller in the 3D group when compared to the 2D group.

DISCUSSION

CT allows for the measurement of real lengths and angles that is not available with conventional 2D cephalometry. Furthermore, 3D CT makes it possible to assess age-related changes and post-surgical changes in patients with facial deformity, regardless of differences in patient position between examinations.[1,15] Studies have shown that the additional spatial information provided by 3D analysis makes it possible to obtain a more accurate assessment of the formation, position, characteristics and dimensions of facial soft tissue as well as the eruption of permanent teeth in all patients using 3D images rather than standard 2D methods.[4,16] Craniofacial CT analysis has also been reported to be an excellent method for quantifying and analyzing surface and deep craniofacial structures, especially in cleft palate patients.[17]

While CT is not routinely recommended, it is helpful in those rare cases where plain films may not be reliable enough to assist in making clinical decisions.[18]

Errors related to projection, landmark identification and measurement technique can affect the accuracy of measurements taken from frontal cephalograms.[19] Probably the most important problem of the PA cephalogram is differential magnification; however, correction of differential magnification is neither widely understood nor routinely practiced.[20] Lateral cephalometric films have been reported to have similar magnification problems.[21] In line with earlier studies[22] 2D PA cephalogram measurements were statistically larger than 3D measurements for all parameters (with the exception of OcP-tilt), with the most noticeable difference (14 mm) in the parameter ZA-AZ. These differences are likely the result of magnification error. Vlijmen et al[22] found statistically significant differences between conventional frontal cephalometric radiographs and CBCT-constructed 3D models for all measurements except antegonial notch and left lateral orbital margin. The authors explained the discrepancies as resulting from differences in how the landmarks are viewed in 2D images (on a single tomographic plane) and 3D images (on multiple planes). For this reason, comparison of 2D and 3D images should be undertaken with great caution.

Reproducing head posture and errors in identifying landmarks have also been shown to be problematic with posteroanterior cepahlograms.[23-25] Major et al[25] found that rotation of the vertical axis did not affect the relationship of landmarks to the best horizontal line, but did affect their relationship to the best vertical line. In a study conducted with dry skulls, van Vlijmen et al[26] showed that patient position, i.e., head tilt/rotation, can significantly influence measurements in frontal cephalometric analysis, and Malkoç et al[27] similarly reported that head rotation is likely to affect both linear and angular measurements in lateral cephalometric analysis. In the present study, most parameters (SN-GoGn, ANB, SNA, Max1-NA, Mand1-NB and interincisal angle) varied significantly between the lateral cephalograms and the 3D images. The higher values in the 2D group may be the result of head rotation and magnification error with the lateral cephalograms. Moreover, the complex struc-

ture of CLP makes it difficult to define this region in cephalometric films.

In a study of 6 human dry skulls comparing cephalometric radiographs and CT imaging processed using Mimics, Varghese et al[14] found linear measurements on spiral CT images to be comparable to anatomical measurements and more reliable than cephalometric measurements, which were acceptable for the midsagittal region in the anteroposterior plane, but which varied significantly from anatomical and CT measurements of most parameters. Another study on dry skulls by Major et al[28] regarding the posteroanterior cephalometric films. Given that landmark identifica-

tion is easier on dry skulls devoid of soft tissue, it is likely that the results of the above-mentioned studies represent the minimum error and for this reason differences of up to four times greater have been reported for some measurements in the presence of soft tissue.[30]

The clinical significance of measurement accuracy varies depending upon the level of accuracy required. For example, if CT data is used for pre-surgical planning, information needs to be sufficiently accurate to prevent surgical interventions that result in insufficient jaw lengthening or shortening that might require additional surgery. Despite the difficulty in accurately identify-

Table 1. Comparison of 2D and 3D cephalometric evaluation for Frontal analysis.

Parameters	Mean± Std. Dev	Median	Minimum	Maximum	test
B3L-B3R (mm) CEPH	27.41±3.56	28.00	23.00	34.00	P<.012*
B3L-B3R (mm) 3D	25.43±2.00	24.72	22.90	28.87	
B6L-B6R (mm) CEPH	54.00±6.96	53.00	42.50	64.50	P<.01**
B6L-B6R (mm) 3D	47.33±3.26	46.37	43.74	52.98	
ImL-ImR (mm) CEPH	82.91±6.87	84.00	72.00	92.00	P<.03*
ImL-ImR (mm) 3D	78.03±4.56	78.65	69.95	83.61	
JL-JR (mm) CEPH	65.00±11.69	70.00	44.50	76.50	P<.02*
JL-JR (mm) 3D	58.96±7.04	59.04	42.54	67.68	
Nasal width (mm) CEPH	29.32±3.47	29.00	24.00	34.50	P<.000***
Nasal width (mm) 3D	23.433.48	22.48	19.79	31.73	
OcP-tilt (mm) CEPH	1.14±0.84	1.00	0.00	2.50	P<.107ns
OcP-tilt (mm) 3D	1.84±0.68	1.95	1.02	3.12	
ZA-AZ (mm) CEPH	128.73±10.66	133.00	111.00	141.00	P<.000***
ZA-AZ (mm) 3D	114.42±5.69	116.79	103.00	120.62	
ZL-MoL (mm) CEPH	70.41±7.12	66.50	60.50	82.00	P<.000***
ZL-MoL (mm) 3D	60.83±4.40	60.72	51.75	67.32	
ZR-MoR (mm) CEPH	70.73±7.36	67.00	60.00	84.00	P<.000***
ZR-MoR (mm) 3D	60.52±4.22	61.26	54.04	68.34	
ZL-ZR (mm) CEPH	93.59±9.65	88.00	80.00	110.00	P<.022*
ZL-ZR (mm) 3D	88.27±4.19	89.29	82.19	94.56	

Table 2. Comparison of 2D and 3D cephalometric evaluation for Mc Namara analysis.

Parameters	Mean± Std. Dev	Median	Minimum	Maximum	test
ANS-Me (mm) CEPH	58.18±7.37	57.00	47.00	72.00	P<.54ns
ANS-Me (mm) 3D	56.82±7.10	56.54	47.91	69.05	
Co-A (mm) CEPH	81.41±7.25	82.50	71.00	91.00	P<.01**
Co-A (mm) 3D	87.21±4.51	89.15	80.26	93.60	
Co-Gn (mm) CEPH	104.14±6.75	105.50	93.00	113.00	P<.93ns
Co-Gn (mm) 3D	104.09±4.37	103.09	99.09	115.23	
Max-Mand (mm) CEPH	22.23±6.62	22.00	12.00	31.00	P<.02*
Max-Mand (mm) 3D	16.87±3.87	16.72	11.46	23.02	
SpPo-GoMe (°) CEPH	69.77±7.69	70.00	56.00	80.00	P<.000***
SpPo-GoMe (°) 3D	48.82±7.38	47.45	37.21	65.82	

ing landmarks in patients with severe maxillary or mandibulary defects, this information is critical for all orthognathic surgery patients, especially CLP patients.[31]

Leonardia et al[32] have stated that it is generally easier to identify landmarks lying on a sharp curve or at the intersection of two curves than landmarks located on flat or broad curves. The same authors noted that points located in areas of high contrast are easier to identify than points located in areas of low contrast and that the mastoid, latero-orbitale and antegonion landmarks are easier to identify than dental landmarks.[32]

The statistically significant differences noted by Steiner analyses of SNGoGN and SNA measurements using 2D and 3D images in the present study may be related to the nature of the point Sella, one of the most important reference points. Although generally considered to be the center of a cephalometric view, Sella Turcica is, in fact, not a planar structure localized on the mid-cranial sagittal plane. This represents a significant difficulty in the assessment of the point Sella on conventional cephalometric film on three-dimensional reconstruction of computerized tomography scans. In line with this, Yitschaky et al[33] found measurements involving Sella Turcica to vary significantly between 2D and 3D images, with the 3D location of the mid-sella point to be more precise using CT.

The distance from the condylion to Point A (Co-A) represents the position of the maxilla in relation to the mandibular condyles. Even if we consider that the crest of the contour of maxillary anterior concavity in the lateral cephalogram can also be determined likewise as a point in the 3D reconstruction, the mandibular condyles are at a great distance from the sagittal mid-cranial plane. However, in lateral cephalograms, this distance is on a 2D plane they are neither in the in vivo situation nor in 3D reconstruction. Considering that it is nearly impossible to separately measure Co-A for the right and left condyles using cephalometric films, the present study calculated a mean value for the separate measurements obtained using 3D images and used this mean value to obtain an accurate comparison between 2D and 3D measurements. When considering the reference points in 3D, we tried to reach to the nearest points corresponding to their 2D cephalometric landmarks in order to maximize the comparability of 2D and 3D measurements. It appears likely that 3D evaluation represents a more accurate method for monitoring craniofacial development than 2D lateral cephalometric films, especially among children with craniofacial deformities, where facial asymmetry is generally more pronounced.

Maeda et al[10] suggested that 3D CT might have a higher sensitivity than PA cephalometric film

Table 3. Comparison of 2D and 3D cephalometric evaluation for Steiner analysis.

Parameters	Mean± Std. Dev	Median	Minimum	Maximum	test
SNA (°) CEPH	75.86±6.44	76.50	64.00	85.50	P<.007**
SNA (°) 3D	77.17±5.61	77.16	67.63	86.67	
SNB (°) CEPH	73.27±4.09	75.00	64.00	77.00	P<.062ns
SNB (°) 3D	74.52±3.14	75.14	68.49	78.22	
ANB (°) CEPH	2.59±4.72	2.00	-7.00	9.50	P<.036*
ANB (°) 3D	2.73±4.80	2.72	-7.57	11.62	
SND (°) CEPH	70.68±3.99	72.00	62.00	74.00	P<.11ns
SND (°) 3D	70.22±4.11	71.75	59.77	73.63	
Max1-NA (°) CEPH	0.55±18.44	6.00	-42.00	24.00	P<.006**
Max1-NA (°) 3D	20.72±7.97	17.73	11.81	37.63	
Max1-SN (°) CEPH	75.91±17.42	82.00	35.00	91.00	P<.286ns
Max1-SN (°) 3D	80.90±9.08	84.42	63.14	89.56	
1-1 (°) CEPH	162.05±15.39	156.50	148.00	192.00	P<.008**
1-1 (°) 3D	140.56±18.91	140.40	109.37	170.41	
Mand1-NB (°) CEPH	17.18±6.25	17.00	7.00	30.00	P<.005**
Mand1-NB (°) 3D	21.62±7.40	23.45	8.10	30.94	
SN-Go-Gn (°) CEPH	35.64±4.67	35.00	30.00	45.00	P<.000***
SN-Go-Gn (°) 3D	48.27±3.31	46.77	43.59	54.62	

imaging in the diagnosis of maxillary asymmetry. For example, on PA cephalograms, it was not possible to evaluate anteroposterior asymmetry, for example, the distance between a landmark and the coronal reference plane, and the authors suggested that because 3D-CT permits more detailed evaluation, it has the potential to replace conventional cephalographic classification of facial asymmetry.[10]

With regard to intra- and inter-observer reliability, the degree of reported variation in landmark identification varies widely among studies. Major et al[28] stated that landmarks with identification errors greater than 1.5 mm should probably be avoided and that landmarks with identification errors greater than 2.5 mm are definitely inappropriate for PA cephalograms. In the present study intra-observer variability was very high; however, the measurements should be analyzed carefully due to the differences found between the groups for clinical evaluation. Each individual landmark is known to have its own characteristic noncircular envelope of error,[29,34,35] and, as Lou et al[29] point out, differences in measurement of short linear distances will be reflected as greater percentages of error than similar absolute differences in measurement of longer distances. Similarly, for angular measurements, the absolute difference in measurement of an acute angle appears as a greater percent of error than that of a more obtuse angle.

In addition to landmark shape, measurement accuracy is also affected by defects and asymmetries. For example, in CLP patients, locating the deepest point of the maxilla (point A) is very difficult. Among the measurements obtained in the present study, the greatest errors were found for SNA angle and Co-A length. Imaging of the premaxillary region in 3D imaging is very different from imaging of 2D cephalometric films. In general, superimposition makes it difficult to accurately identify upper incisor position on cephalometric films, and in the present study, excessive inclination and rotation in CLP patients added to the difficulty of accurately determining the position of the upper incisors, which explains the statistically significant differences in maxillary incisor measurements between the 2D and 3D groups.

Other factors involved in landmark identification accuracy include clinical experience,[28] the clarity of the definition used to describe the landmark, image quality, the geometry (straight or ovoid) of the object to be identified and the contrast between adjacent objects.[36] In the present study, for instance, the deepest point of the maxilla (jugular point) used in frontal analysis appeared as a fossa in the 3D image, but as a point in the cephalometric films. Similarly, due to the 3D nature of the meatus acusticus externus, the point Porion appeared in different locations in the 2D and 3D images. This would explain the great variability between 2D and 3D measurements of the parameter SpPo-GoMe in the present study (Table 2). Another reason for this variability could be the fact that SpPo-GoMe is located in different tomographic planes, as discussed above.

Troulis et al[37] stated that 3D-CT driven software has great potential for use in the diagnosis and analysis of congenital and acquired craniomaxillofacial skeletal deformities; for the calculation of vectors of surgical movement, localization of osteotomies and placement of distraction devices as part of surgical treatment planning; and, possibly, as a basis for a surgical navigation system. The CT images taken in the present study were used by plastic surgeons for treatment planning.

If standard and repeatable reference points can be obtained, 3D cephalometric evaluation can provide accurate data on craniofacial measurements, as other studies have suggested.[38,39] However, major concerns continue to exist regarding their widespread usage.[1,2,5,12] First, CTs expose patients to considerably higher amounts of radiation than conventional cephalograms. This limits the number of CT scans that can be taken over short intervals to monitor craniofacial development, especially in growing children. Second, CT scans requires very expensive equipment, making the cost of an individual CT scan much more expensive than a lateral cephalogram. For this reason, CBCT seems likely to replace medical CT for use in orthodontics and plastic surgery in the near future. Perhaps most important, there is still a need for the establishment of widely accepted reference points and norms appropriate for 3D evaluation in order to facilitate the consistency of inter-method evaluation.

CONCLUSIONS

This study found significant differences between measurements made on 2D and 3D images taken of CLP patients. Although there are some previous studies reporting that cephalometric and three-dimensional evaluations show a considerably well correlation, but one should be very careful when interpreting the results.

This can be due to the fact that the subjects of this study are consisted of children with cranio-facial anomalies while all the norms in conventional cephalometric analyses are considered on normal subjects.

Within the limitations of this study, it can be concluded that further studies are needed in order to more accurately determine the anatomical landmarks on the three dimensional reproduction and thus to establish new standards for 3D evaluations of CLP patients.

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