Open Journal of Stomatology, 2017, 7, 186-196
http://www.scirp.org/journal/ojst
ISSN Online: 2160-8717
ISSN Print: 2160-8709

A Comparison between 2D and 3D Images to Study Maxillary and Mandibular Widths: A Pilot Study

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How to cite this paper: Al Mawaldi, I., Tabbaa, S., Preston, C.B. and Salti, M. (2017) A Comparison between 2D and 3D Images to Study Maxillary and Mandibular Widths: A Pilot Study. *Open Journal of Stomatology*, **7**, 186-196.
https://doi.org/10.4236/ojst.2017.73014

Received: February 16, 2017
Accepted: March 28, 2017
Published: March 31, 2017

Abstract

The objective of this study is to compare the transverse dimensions of the jaws, obtained from traditional posteroanterior (PA) cephalometric radiographs, and with the similar respective measurements obtained by means of cone beam computed tomography (CBCT). Data of twelve subjects were selected from the clinical records of Orthodontic Department. All of the subjects had their permanent teeth in occlusion and had good quality regular (2D), and CBCT (3D) images as part of their initial records. Subjects were divided to a posterior cross-bite and non-cross bite groups. The ratio of the maxillary, to mandibular transverse widths was calculated for the sample. In subjects without dental cross-bites the average ratio of the maxillary, to mandibular jaw widths was 0.75 on the standard radiographs and 1.04 on the CBCT scans. In subjects with dental cross-bites the average ratio of these widths was 0.70 on the standard radiographs and 0.9 on the CBCT scans. The ratios of the maxillary, to mandibular widths differ when obtained from conventional cephalometric radiographs as compared to the respective ratios obtained from CBCT scans. Maxillary, to mandibular width ratio is in the order of 1:1 as determined by means of CBCT scans.

Keywords

Posteroanterior Cephalometric (PA) Radiograph, CBCT, 2D, 3D, Transverse Jaw Measurements, Posterior Cross-Bite

1. Introduction

Although orthodontists tend to rely on lateral and anteroposterior cephalometric radiographs to determine the existence, and degree, of craniofacial abnormality that is present in their patients, several limitations are inherent in the use of these means of records in a clinical setting. Such limitations are frequently linked to the fact that it can be more or less impossible to identify, with the required accuracy, many of the landmarks that constitute a particular cephalometric analysis [1]-[11].

During the past decade CBCT, which has evolved from medical computed tomography [12] has become a part of the diagnostic methods that are available to orthodontists. There is the expectancy that these new developments may eliminate some of the shortcomings that are associated with conventional radiographs of the facial region [9]. The accuracy and reliability of CBCT images have been tested and were found to be adequate for implant planning, periodontal disease quantification, and assessment of the volumes of tumors. Moreover, the reconstructed CBCT images are accurate and reliable when compared with the respective conventional radiographs of the same region. Commercially available software makes it possible to take full advantage of CT scans in performing 3D measurements and in developing 3D craniofacial analyses [13]. For this, and other reasons, a trend has developed to change from traditional 2D analog films to 3D digital imaging systems.

Transverse problems, such as posterior cross-bite, are a great concern to orthodontists and have been mentioned as having very real potential for relapse [7]. In addition, posterior cross-bites CBs have been reported to be represented in most of prevalent malocclusions of the primary dentition in White children and there is the possibility that, if left untreated, cross-bites may lead to craniofacial asymmetry [14]. As unilateral cross bite commonly arises as a result of a relatively narrow maxilla, the relationship between the widths of maxillary and mandibular skeletal bases is presumably the most critical information sought from the PA cephalometric record [14] [15].

In order to identify, and quantify skeletal discrepancies and facial asymmetries there have been attempts to develop cephalometric analyses applicable to the transverse craniofacial measurements [7] [14] [16]. Thus, the presence of a small maxillary to mandibular skeletal width ratio could indicate the existence of a skeletal component in the presence of a dental cross-bite. This finding could have important clinical implications regarding early verses late treatment. On the other hand, if the review of the records reveals a larger than or normal ratio, the posterior cross-bite would be more likely of a dental nature [8] [14] [17].

But then studies [2] pointing to the inherent limitations of two dimensional techniques that are used currently to determine facial asymmetry arise the challenge that faces orthodontics to understand, and reconcile, two dimensional cephalometric measurements with the volumetric environment of CBCT scans. The selection of anatomical landmarks used in three dimensional cephalometric analyses tends to follow the definitions that apply to the respective anatomical landmarks used in conventional cephalometric analyses [11].

Recently Andrews described an anatomic ridge on the mandibular alveolar process that corresponds in position to a soft-tissue band that is usually located immediately superior to the mucogingival junction [17]. This soft-tissue structure was called the WALA ridge after Will, and Larry Andrews who jointly proposed this ridge, although being present in both jaws, as a reference line for determining the morphology of the mandibular dental arch. The WALA ridge approximates the supero-inferior position of the centers of rotation of the mandibular teeth and it has been suggested that this anatomical feature presents a useful guide as to the appropriate width of the mandibular basal bone [18]. The WALA ridge is easy to identify on CBCT scans oriented in the coronal plane of the skull and it may prove useful in determinations of the required jaw widths for orthodontic patients.

The purpose of the present pilot study was to compare the transverse measurements of the mandibular and maxillary jaws as obtained from conventional PA cephalometric radiographs with the respective corresponding measurements obtained by cone beam computer tomography CBCT.

2. Materials and Methods

The records of twelve subjects were included in this pilot study. The subjects included in this study were the first twelve patients who had complete initial records of sufficient quality to allow for the required measurements to be made. Informed consents were obtained from all patients. The appropriate records included posteroanterior 2D radiographs of suitable quality, CBCT scans of the craniofacial structures and study models. Study models were used to determine the presence or absence of posterior crossbites in addition to clinical examination. The subjects included in this investigation had all of their permanent teeth in an occlusion up to, and including, their first permanent molars. Patients with missing permanent molar teeth, with craniofacial deformities and with PA radiographs with indications that their head may have been misaligned during exposure of the radiograph were excluded from this study. Seven of the twelve subjects selected for this study had good posterior dental over jet and these patients formed a subgroup of non-posterior cross-bite patients. The remaining five patients included in this study had study models that demonstrated the presence of posterior cross bites. The presence of posterior cross bite was defined as a minimum of two teeth in unilateral or bilateral lingual cross bite or edge to edge cusps, based upon plaster or Ortho-cad™ models and clinical evaluation. Cephalograms were traced and measured by hand, and all measurements were made by a single investigator (I.M). The enlargement factor for the cephalometric radiographs was calculated at 8%. Landmarks (JR, JL, AgR, AgL) and measurements (JL-JR, Rag-LAg) to assess transverse discrepancies between the maxilla and the mandible were chosen according Ricketts PA cephalometric analysis [16] [19] [20]. To assess skeletal constriction, the ratio (JL-JR/Rag-LAg) between the maxillary and mandibular widths was computed (Norm JL-JR/RAg-LAg = 80%) [20] (**Figure 1**).

The CBCT scans used in this study were obtained by means of an I-Cat™

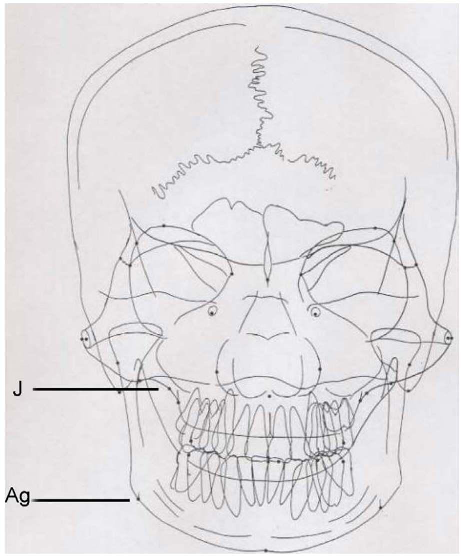

Figure 1. Posteroanterior (PA) cephalometric landmarks used in the study (J, Ag).

scanner (Imaging Sciences International, Inc., Hatfield, PA, USA). The field size was set at 8 cm ad the voxel size at 0.4 mm. The resultant DICOM data were manipulated with the software supplied with the scanner in order to produce slices of 1.5 mm depth in the coronal plane. The widths of the maxillary and mandibular basal bones were measured from the CBCT scans in two different ways. Firstly, CBCT slices were selected from each subject's DICOM data that best represented the dimensions JL-JR and Rag-LAg. The proprietary software provided with the scanner was used to provide the measurements between the respective sets of landmark points. Secondly, the maxillary, and mandibular basal bone widths were measured at the levels of the respective WALA ridges and on the slices, that corresponded to the bifurcation of the respective first molar teeth (UTm = upper transverse measure, LTm = lower transverse measure) (Figure 2).

3. Statistical Analysis

To assess the reproducibility of the measurements made in this study, each set of measurements was repeated for each of the subjects included in this study. Dahlberg's Standard Deviation (method error ($ME = \sqrt{\left\{\sum d_i^2 / (2 * n)\right\}}$) was calculated for each of the duplicate sets of data [21].

Comparison of ratios between the Normal and Cross Bite subjects was done using the two independent samples Student's t-test. Comparison of the 2D with the 3D ratios was done using the paired samples Student's t-test. All tests were performed at the 5% level of significance. The descriptive statistics provided included the means, standard deviations (SD) and Pearson correlation coefficients. All statistical analyses were performed using version 16.0 of the SPSS (Statistical Package of the Social Sciences, an IBM™ company) statistical software.

The present study was approved by the Health Sciences Institutional Review

Board (HSIRB) of the State University of New York at Buffalo (HSIRB project #ORT0180610E).

4. Results

The results of the determination of the method error (Table 1) show that the standard deviations are less than 0.5 mm for the measurements J-J, UTm and LTm and slightly greater than 0.5 mm for the measurements Ag-Ag. This observation indicates that the error of the method is likely to be less than 1.5 mm for all of the measurements made in this study. With regard to the ratios, each error is very small, 0.0092 and 0.0070 for the 2D and 3D methods respectively.

The individual 2D means for the jaw width ratios for each of the seven non crossbite subjects (Table 2) ranged from 0.644 to 0.818 (average 0.7462; SD 0.0663). For the five crossbite subjects (Table 3(a)) the jaw width ratios ranged from 0.644 to 0.791 (mean 0.7331; SD 0.055). Based on a two independent samples t-test (Table 3(b)) there was no significant difference between the two groups ($P = 0.726$).

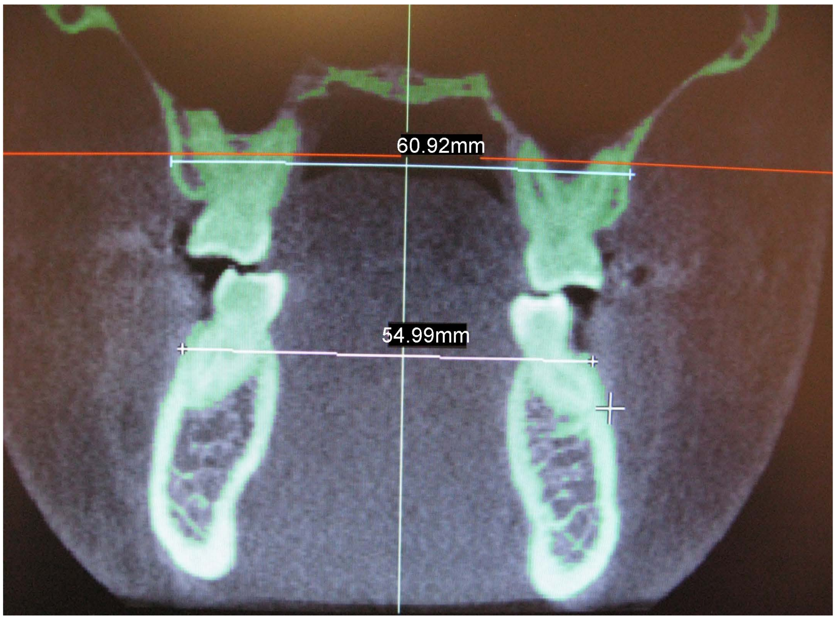

Figure 2. Measurements of the basal bones from the CBCT scans (UTm = Upper transverse measure, LTm = Lower transverse measure).

Table 1. Method of the error estimates.

	Method Error
J-J	0.3227
Ag-Ag	0.6374
Ratio	0.0092
UTm	0.2868
LTm	0.4463
Ratio	0.0070

Table 2. Descriptive statistics for the 2D PA measurements of J-J, Ag-Ag, and their ratios (J-J/Ag-Ag) in the non crossbite subjects (S).

S	J-J	Ag-Ag	Ratio
1	49.25	68.75	0.716
2	54.75	68.00	0.805
3	64.00	86.25	0.742
4	52.75	64.50	0.818
5	48.75	60.50	0.806
6	47.25	68.25	0.692
7	49.75	77.25	0.644
Mean	52.357	70.500	0.7462
Std. D.	5.730	8.602	0.0663

Table 3. (a) Descriptive statistics for the 2D PA cephalometry of J-J, Ag-Ag, and their ratio (J-J/Ag-Ag) in crossbite subjects (S); (b) Comparison of 2D measurements between non-crossbite, and crossbite subjects.

(a)

S	J-J	Ag-Ag	Ratio
1	46.75	72.50	0.644
2	50.25	66.00	0.761
3	35.25	47.25	0.746
4	49.25	62.25	0.791
5	50.00	69.25	0.722
Mean	46.300	63.450	0.7331
Std. D.	6.330	9.822	0.0553

(b)

Group	N	Mean	Std. Deviation	Std. Error Mean	Mean Diff.	t	*p*-value
Normal	7	0.746211	0.0663452	0.0250761	0.0131288	0.361	0.726
Cross Bite	5	0.733082	0.0553451	0.0247511			

The individual 3D measurements and ratios for each of the non crossbite subjects are presented on **Table 4**, while the same information for the crossbite subjects is presented on **Table 5(a)**. For the seven non crossbite subjects the ratios varied from 0.9447 to 1.1117 (average 1.0398; SD 0.0660) while for the five crossbite subjects the ratios varied from 0.8952 to 0.9831 (average 0.9211; SD 0.0358). The difference between the two groups was statistically significant ($P =$ 0.005, **Table 5(b)**).

When comparing the 2D and the 3D ratios for all subjects it was noted that the 3D ratios were significantly ($P < 0.001$) greater than the 2D ratios (difference = −0.25). The correlation for the measurements in these subjects was a modest 0.450 (**Table 6**). When comparing the 2D and 3D ratios for the seven non crossbite subjects it was noted that the 3D ratios were significantly ($P < 0.001$) greater than the 2D ratios (difference = −0.29). The correlation between these ratios was

0.647 (Table 7). When comparing the 2D and 3D ratios for the five crossbite subjects it was noted that the 3D ratios were significantly ($P = 0.002$) greater than the 2D ratios (difference = −0.19). The correlation for these ratios in this group was 0.614 (Table 8).

Table 4. Descriptive statistics for the 3D CBCT scan of UTm, LTm, and their ratio (UTm/LTm) in non crossbite subjects (S).

S	UTm	LTm	Ratio
1	57.305	51.545	1.111747
2	60.750	54.955	1.1055
3	58.325	57.365	1.0167
4	59.535	54.135	1.0998
5	55.490	54.820	1.0122
6	54.140	54.805	0.9879
7	57.230	60.580	0.9447
Mean	57.539	55.458	1.0398
Std. D.	2.266	2.829	0.0660

Table 5. (a) Descriptive statistics for the 3D CBCT scan of UTm, LTm, and their ratio (UTm/LTm) in crossbite subjects (S); (b) Comparison of 3D measurements between non-crossbite, and crossbite subjects.

(a)

S	UTm	LTm	Ratio
1	50.640	56.265	0.9000
2	55.650	61.24	0.9087
3	54.155	55.085	0.9831
4	50.120	54.575	0.9184
5	59.510	66.48	0.8952
Mean	54.015	58.729	0.9211
Std. D.	3.855	5.074	0.0358

(b)

Group	N	Mean	Std. Deviation	Std. Error Mean	Mean Diff.	t	*p*-value
Normal	7	1.039782	0.0659720	0.0249351	0.1187038	3.627	0.005
Cross Bite	5	0.921078	0.0357910	0.0160062			

Table 6. Comparison of 2D with 3D measurements for all subjects.

Group	N	Mean	Std. Deviation	Std. Error Mean	t	*p*-value	Correlation
Ratio 2D	12	0.740740	0.0596697	0.0172251	−11.374	<0.001	0.450
Ratio 3D	12	0.990322	0.0810922	0.0234093			

Table 7. Comparison of 2D with 3D measurements for non crossbite subjects.

Group	N	Mean	Std. Deviation	Std. Error Mean	t	*p*-value	Correlation
Ratio 2D	7	0.746211	0.0663452	0.0250761	−13.969	<0.001	0.647
Ratio 3D	7	1.039782	0.0659720	0.0249351			

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Table 8. Comparison of 2D with 3D measurements for cross bite subjects.

Group	N	Mean	Std. Deviation	Std. Error Mean	t	*p*-value	Correlation
Ratio 2D	5	0.733082	0.0553451	0.0247511	−7.522	0.002	0.614
Ratio 3D	5	0.921078	0.0357910	0.0160062			

5. Discussion

The present pilot study was designed to compare maxillary and mandibular widths as determined from traditional 2D cephalometric radiographs and 3D volumetric CBCT scans, respectively. The sample studied ($n = 12$) included seven subjects without dental crossbites and five subjects with crossbites. Measurements made on the radiographs were the traditional landmarks (Jugale and Antegonion) proposed by Ricketts [16] [19] [20]. The ratio of the maxillary, to the mandibular, widths were calculated (ratio = JL-JR/Rag-Lag × 100) for each of the subjects in the study. While many measurements have been proposed to study the widths of the jaws, the individual jaw width measurements and jaw width ratio used in the present study has stood the test of time and seems to be the most widely used [8] [17] [19]. According to Ricketts [19] [20] the normal value for the maxillary, to mandibular width ratio (JL-JR/Rag-LAg) as obtained from a posterior-anterior cephalometric radiograph is in the order of 80% from three years to 18 years of age.

In a cephalometric study carried out on young adult patients with ideal occlusions the average value for the jaw width ratio was determined to be 74.9% ± 3.8% at the age of 18 years [8]. In a more recent study that ratio was reported to be 0.78 in a control group and 0.69 in a group of subjects with dental crossbites [2]. The Rocky Mountain™ data system analysis, used to study the transverse relationship between the jaws, includes the average values for these data for the age groups nine to 16 years which is 0.77 [22]. In the present study, the mean jaw width ratio was found to be 0.7462 ± 0.0663 in non crossbite subjects and 0.7331 ± 0.0553 in subjects with crossbites. The patients who were included in the cross-bite group had mean values for the jaw width ratio that were significantly ($P \leq 0.05$) below the value for this ratio proposed by Ricketts [19] [20]. Whereas some patients in the normal group had jaw width ratios that were also relatively low they did not display overt dental crossbites and they were not treatment planned to undergo rapid maxillary expansion.

From a review of the literature it appears that CBCT scans could enhance the ability of clinicians to locate the landmarks that are required to calculate a jaw width ratio [13] [23]. It was thus decided to use CBCT scans in a pilot study to assess the feasibility of using the traditional landmarks to determine the transverse dimension of the jaws and, if possible, to use these dimensions to calculate the jaw width ratios. In practice, it is difficult to determine the exact locations of the landmarks proposed by Ricketts to measure the upper and lower jaw widths. The point "J" is defined by the overlap of two anatomical structures that do not fall on a single CBCT slice in the coronal plane with a dimension less than 3.0 mm. When trying to determine the position of "Ag" the problem arises that it is not possible to determine the deepest point of the antegonial notch on a single CBCT slice in the coronal plan. For this, we were faced with the need to find new reliable landmarks which represent the actual transverse dimension of the jaws and are easy to locate on one single CBCT slice.

The WALA ridge points lie in close proximity to the supporting bone of the upper and lower jaws and they may provide useful information as to the individual widths of the jaws and as to the respective jaw width ratios. In practice, it is relatively easy to find the WALA ridges on coronal slices of the jaws as produced through CBCT scans. On the other hand, the bifurcation of the first molar teeth can also be identified consistently on coronal CBCT slices of the facial skeleton. In the present study, we incorporated both these facts by using the WALA ridges in the coronal slice that corresponds to the bifurcation of the upper first molars to define new points that were used to measure the width of maxillary and mandibular jaws.

We took in consideration the fact that, in crossbite cases, rotations, tipping and buccolingual position of molars may complicate accurate determination of the molar bifurcation and consequently the correspondent jaw widths. But as this is a pilot study of small number of cases, it was relatively easy for the investigators to choose the slice which contained the bifurcations of both the right and the left upper first molar.

Using the 3D measurements, this study showed that in non crossbite subjects the jaw width ratios varied from 0.9447 to 1.1117 (average 1.0398; SD 0.0660) while for the five subjects with crossbites the ratios varied between 0.8952 to 0.9831 (average 0.9211; SD 0.0358). The difference in the jaw width ratios between the non crossbite subjects and the crossbite subjects was statistically significant ($P = 0.005$).

The individual jaw widths and the jaw width ratios as determined from the CBCT scans seem to reflect, with a greater degree of objectivity, the effective dimensions of the jaws and their contained dental arches. When the jaw width ratio is 1.00 it implies that the width of the maxillary basal bone is equal in width to the same structure in the mandibular jaw. When this ratio is greater than 1.0 it implies that the upper arch is wider than the lower jaw in the region of the coronal CBCT slice. Conversely, a jaw width ratio less than 1.0 would point to an understanding that the width of the upper jaw is relatively narrower than the width of the lower jaw in a respective coronal CBCT slice.

The results of this pilot study are in agreement with the belief expressed by Andrews [18] that the widths of the jaws should be measured directly from the jaws in the coronal plane and probably in the region of the so-called WALA ridges.

6. Conclusions

1) The maxilla to mandible width true ratio is only slightly greater than 1.0 as measure on a CBCT scan in the coronal plane.
2) CBCT images can provide accurate locations of transverse facial cephalome-

tric landmarks and make it possible to assess the transverse relationships of the jaws objectively.

3) Although further studies are needed in this aspect it appears that dental crossbites are due largely to dental alveolar, rather than a skeletal discrepancy.
4) WALA ridge points may well point to the region on the alveolar bone where jaw widths should be determined.

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