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Comparison of Digital and CBCT Synthesized Lateral Cephalograms

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Comparison of Digital and CBCT Synthesized Lateral Cephalograms

by

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A Dissertation submitted in partial satisfaction of
requirements for the degree
Master of Science in Orthodontics and Dentofacial Orthopedics

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Each person whose signature appears below certifies that this thesis in his opinion is adequate, in scope and quality, as a thesis for the degree Master of Science.

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ABSTRACT OF THE THESIS

Comparison of Digital and CBCT Synthesized Lateral Cephalograms

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Master of Science
Graduate Program in Orthodontics and Dentofacial Orthopedics
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Dr. V. Leroy Leggitt, Chairperson

Purpose: The purpose of this study was to compare the precision of lateral cephalometric Ricketts analysis measurements from NewTom 5G CBCT (NewTom) synthesized lateral cephalograms with Sirona Orthophos XG Plus (Sirona) digital lateral cephalograms.
Materials & Methods: A Sirona digital lateral cephalogram and a NewTom synthesized lateral cephalogram of a phantom in the orthogonal and perspective projections were created. Metal washers in each plane of the phantom were measured in the vertical and horizontal dimensions and compared across the different imaging modalities.

In Group 1, forty patients were randomly selected from the Loma Linda University Graduate Orthodontic Clinic who had both a NewTom synthesized lateral cephalogram and a Sirona digital lateral cephalogram. In Group 2, forty patients with both a NewTom and a Sirona lateral cephalogram were selected based exclusion criteria which included images with significant overlap of the first molars and/or border of the mandible, and missing first molars to limit error in cephalometric measurement. All of the lateral cephalograms were digitized into Dolphin 3D version 11.5 and traced using Ricketts cephalometric analysis. For both groups, six linear and nine angular measurements from each imaging modality were compared and analyzed using a paired-t test.

Results: There is a statistical difference in % magnification of washer measurements in the horizontal and vertical dimensions amongst the caliper measurements versus various imaging modalities. In Group 1 and Group 2, all of the linear measurements except lower lip to E-plane were statistically different ($P < 0.05$). The angular measurements were not statistically different ($P < 0.05$) with the exception of Ricketts facial axis ($P = 0.001$), lower face height ($P = 0.027$), and mandibular arch ($P = 0.029$) for Group 1. The angular measurements were not statistically different ($P > 0.05$) with the exception of Ricketts facial axis ($P = 0.020$), interincisal angle ($P = 0.044$), and lower face height ($P = 0.043$) for Group 2.

Conclusions: The statistical differences found in this study translate to clinically significant differences that will likely make superimpositions difficult and therefore the reference line used for calibrating magnification for the various image modalities should be recalibrated.

CHAPTER ONE

INTRODUCTION

Conventional two-dimensional (2D) cephalometric analyses have been a critical tool in orthodontic diagnosis and treatment planning for many years. In the past decade, three-dimensional (3D) cone beam computed tomography (CBCT) has become increasingly popular in the field of dentistry due to its high-resolution imaging, diagnostic reliability, and favorable risk-benefit assessment.[1,2] In orthodontics, CBCT has become a useful tool for impacted teeth, temporomandibular joint evaluations, airway volume analyses, assessment of craniofacial growth and development, and simulations for orthodontic surgical planning.[3] Another critical benefit of the CBCT is the ability to utilize the 3D image to also synthesize 2D images that would otherwise be obtained from conventional panoramic and cephalometric machines, thus allowing conventional superimpositions with 2D cephalometric images when needed.

Drawbacks of Conventional 2D Lateral Cephalograms

Conventional 2D lateral cephalograms have several drawbacks such as errors in patient positioning which could distort images, differential magnification of bilateral structures with imperfect superimposition of the right and left sides, and inaccuracies in landmark localization due to superimposition of craniofacial structures.[4-6] However, these conventional cephalograms have been used for orthodontic diagnosis because they enable spatial evaluation of the craniofacial and dental structures. Another limitation of conventional 2D methods is that a 3D structure is collapsed into a 2D plane thus distorting the proportion and magnification of the image. This distortion is eliminated in CBCT synthesized lateral cephalograms when used as a 1:1 image. Studies by Kumar et al. have shown that measurements obtained from CBCT generated images do not differ from actual skull measurements and that they are similar in precision and accuracy when compared to conventional cephalograms.[7,8] Therefore, then, the question to be addressed is why not replace conventional radiographs with CBCT 3D imaging?

Transitioning from 2D to CBCT

There are several considerations to be addressed before transitioning from conventional to CBCT synthesized cephalograms. One concern that arises with CBCT use for routine orthodontic assessment is whether it follows the principle of "as low as reasonably achievable" (ALARA). The radiation dose with CBCT has been reported to be 40% less than conventional CTs but three to seven times more than panoramic doses.[9,10] A study by Silva et al which compared radiation doses for conventional panoramic and cephalometric imaging with CBCT and multi-slice CT units concluded that strictly from a radiation dose standpoint, the routine use of CBCT for orthodontic diagnosis is not recommended because conventional panoramic and cephalometric images deliver lower doses.[3] However, the validity of CBCT use for diagnostic purposes is debatable. In cases where additional information regarding impacted teeth, root resorption, ankylosis, temporomandibular joint evaluation, airway evaluation and or surgical planning is needed, CBCT scans are necessary and beneficial. Furthermore, there are patients that require more radiographic images than the standard panoramic and cephalometric X-rays. Some orthodontic patients need a series of temporomandibular joint images, periapical radiographs, bitewing radiographs, occlusal radiographs and/or a combination of the above. In cases where a panoramic, lateral cephalometric and periapical images are needed, the sum of the effective doses for all three range similar to or higher than that of a CBCT scan. A study by Ludlow et al. has shown that the radiation dose from CBCT can be less than the dose delivered from a full mouth periapical series using D-speed film and round collimation.[11] In such cases, it would be advantageous to use a CBCT scan which will deliver the same or even lower doses of radiation while providing 3D evaluation. Furthermore, with an increase in the volume of adult patients seeking orthodontic treatment, the need for periapical X-rays along with a panoramic and cephalometric radiograph becomes higher. In order to uphold the standard of care as presented by the American Board of Orthodontics for patients 18 years or older and younger patients with signs and symptoms of periodontal involvement, patient records should have periapical and bitewing radiographs or a record of full-mouth periodontal probing.[12] Thus in many orthodontic cases, especially those of adult patients, the benefits of a single CBCT scan outweigh the risks of exposing the patient more radiation.

Another concern of transitioning from 2D to CBCT synthesized lateral radiographs is the matter of how cephalometric analyses of CBCT derived cephalograms compare to existing databases of conventional cephalograms. Uncertainty of the accuracy and reliability of CBCT synthesized cephalograms hinder many orthodontic practices from transitioning from conventional radiographs to 3D capable devices. However, there have been numerous studies that have demonstrated the accuracy and precision of CBCT synthesized cephalograms. Moshiri et al. reported that CBCT derived cephalograms are generally more accurate than conventional digital cephalograms when comparing direct measurements on skulls.[13] Another study conducted by Lamichane et al. concluded that the high accuracy of constructing a perspective cephalogram from an i-CAT CBCT scan enables its replacement of 2D cephalograms for normative date or serial records.[14] Lagravere et al. evaluated the accuracy of the NewTom CBCT and reported a 1-to-1 image-to-reality ratio.[15] Studies have shown that CBCT images provide 1:1 geometry. Many studies have proven the accuracy of CBCT synthesized lateral cephalograms. However, digital cephalometric machines have various specifications of magnification.[16]

CBCT imaging has substantial advantages for orthodontic diagnoses and comprehensive treatment. Furthermore, updated software allows clinicians to take full advantage of CBCT scans in deriving an array of information and obtaining accurate measurements as well as measurements that are comparable to measurements obtained from conventional cephalograms. The capabilities of CBCT machines and updated software aid in creating a smooth transition from conventional digital lateral cephalograms to CBCT synthesized lateral cephalograms.

Cephalometric analyses are important in diagnosing and treatment planning in orthodontics. As technology advances and provides clinicians with additional tools to assess and diagnose patients, clinicians should be aware that these advanced technologies may not translate as essentially equal to that of the current of the gold standards for treatment. With the growth of CBCT technology and its increasing capabilities, a transition from conventional 2D cephalometric machines to CBCT is a realistic future. No study has compared the NewTom 5G synthesized lateral cephalogram and the Sirona Orthophos XG Plus digital lateral cephalogram Ricketts Analysis measurements.

CHAPTER TWO

MATERIALS AND METHODS

Box Construction

A gridded 3D imaging object was constructed to serve as a radiographic phantom. For the phantom construction, two outside layers of cardboard, three layers of 1.3 cm wire-grid mesh and two Styrofoam layers 5.1 cm thick were cut into 17.8 cm by 16.5 cm squares (Fig 1).

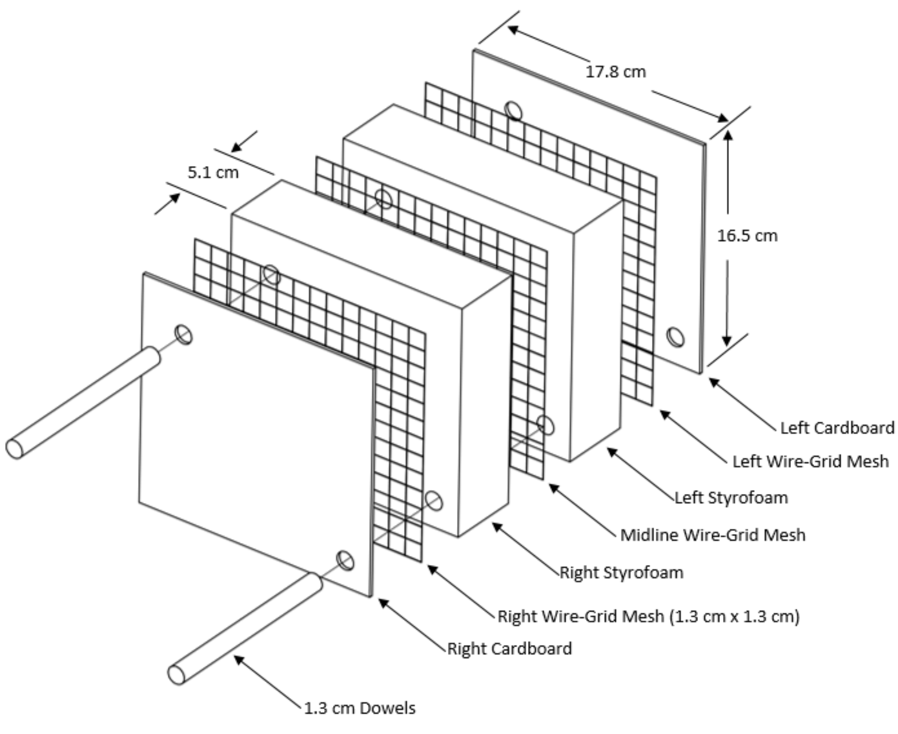

Figure 1. Exploded view of the 3D imaging phantom.

The three wire-grid mesh layers were designated as the Right, Midline, and Left wire-grids. The Right wire-grid had two beveled washers of the same size taped within the wire-grid squares with one washer in the selected Porion location and the other washer in the selected Molar position (Fig 2).

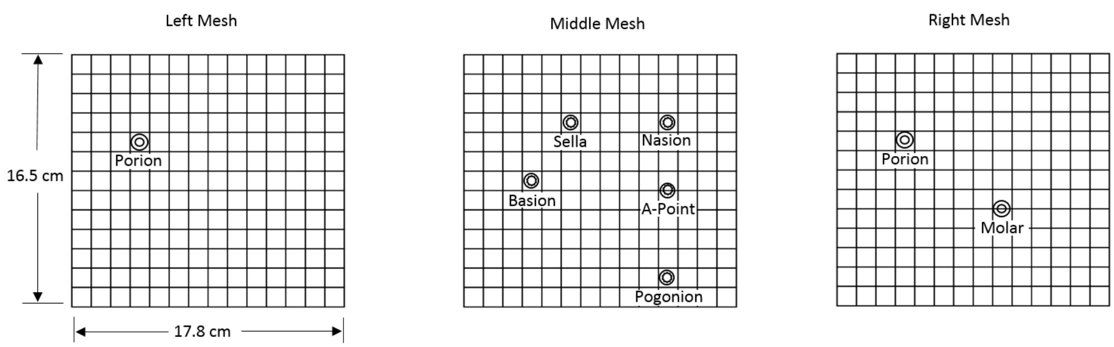

Figure 2. Designated washer locations for each wire-grid mesh layer.

Midline wire-grid had five washers of the same size with internal teeth to distinguish them from the washers in the Right and Left wire-grids, and they were taped into place in designated locations for Basion, Sella, Nasion, A-point, and Pogonion (Fig 2). The Left wire-grid had one beveled washer of the same size as the washers in the Right wire-grid and it was taped in the selected Porion location (Fig 2). Each washer in the three wire-grids was measured with a digital caliper 10 times to record the diameter. Porion locations were marked on the external surface of the two cardboard layers. Then the cardboard layers were placed adjacent to the Right and Left wire-grids to serve as the outer layers. The Styrofoam layers were placed between the Right wire-grid and the Midline wire-grid as well as between the Left wire-grid and the Midline wire-grid. Two wooden dowels positioned diagonally from each other were inserted through all the layers for stability. The layers were stacked and then taped to construct the phantom box.

A digital lateral cephalogram with Sirona Orthophos XG Plus (Sirona Dental Systems Inc, NY) and a synthesized lateral cephalogram with NewTom 5G CBCT (Biolase, CA) in both the orthogonal and perspective projections of the box phantom were imported into Dolphin 3D version 11.5 (Dolphin Imaging & Management Systems, Chatsworth, Calif). The digital lateral cephalogram of the phantom was printed and the vertical as well as the horizontal measurement of each washer in the three wire-grids were measured with a digital caliper and repeated 10 times. Once the orthogonal and perspective projections of the CBCT synthesized lateral cephalograms were produced, the washers were digitally measured in Dicom in both the vertical and horizontal dimensions and repeated 10 times.

Intraexaminer and Interexaminer Reliability

To test intraexaminer reliability, five randomly selected digital lateral cephalograms were traced via Dolphin™ 3D 11.5 by one examiner (D. L.) for the Ricketts analysis. The Ricketts Analysis points and planes are shown in Fig.3.

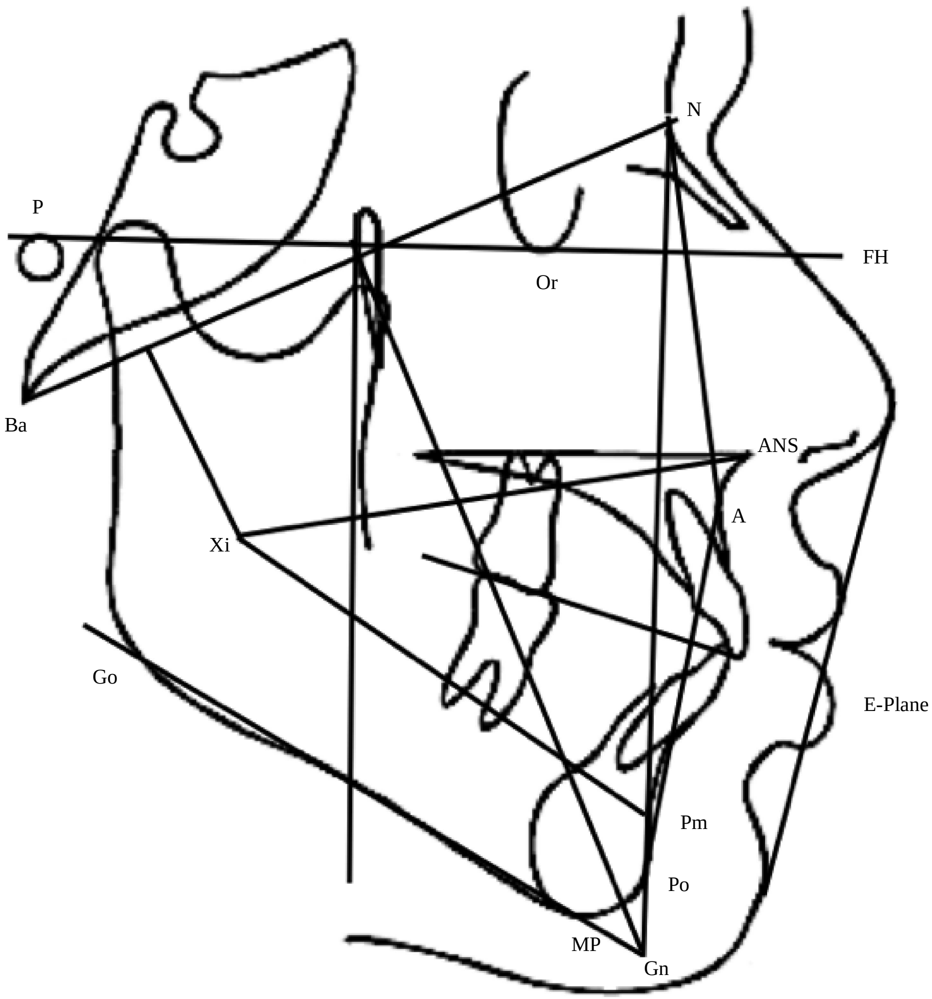

Figure 3. Anatomic landmarks and planes used in Ricketts cephalometric analysis.

The same set of lateral cephalograms was traced two additional times with at least a week's separation between sessions for a total of 15 tracings and 225 measurements. To measure interexaminer reliability, Dr. Leggitt, professor of Orthodontics and Dentofacial Orthopedics, at Loma Linda University, traced the same set of five lateral cephalograms.

Group 1: Randomly Selected Subjects

Forty patients who had both a full-head NewTom 5G CBCT scan and a digital lateral cephalogram from Sirona Orthophos XG Plus were randomly selected from the Loma Linda University Graduate Orthodontic Clinic patient database. For each subject, a NewTom 5G CBCT synthesized lateral cephalogram in the perspective projection with the projection center centered at the midline was imported into Dolphin™ 3D 11.5. The Sirona Orthophos XG Plus digital lateral cephalograms and the NewTom5G CBCT synthesized lateral cephalograms were traced in the Ricketts analysis. For the same forty patients, the Sirona Orthophos XG Plus digital lateral cephalograms were traced in the Ricketts analysis. Linear and angular measurements (Table 1) including vertical and sagittal components were compared between the NewTom 5G CBCT synthesized lateral cephalograms in the perspective projection where the projection center was centered at the midline and the Sirona Orthophos XG Plus digital lateral cephalograms.

Table 1. Ricketts analysis measurements.

Linear Measurements (mm)
1. Convexity (A-NPo)
2. Cranial Length
3. L1 Protrusion (L1-APo)
4. Lower Lip to E-Plane
5. U-Incisor Protrusion (U1-APo)
6. U6-PT Vertical

Angular Measurements (°)
1. Cranial Deflection
2. Facial Angle (FH-NPo)
3. Facial Axis-Ricketts (NaBa-PtGn)
4. FMA (MP-FH)
5. Interincisal Angle (U1-L1)
6. L1 to A-Po
7. Lower Face Height (ANS-Xi-Pm)
8. Mandibular Arc
9. Maxillary Depth (FH-NA)

Group 2: Subjects with Specified Exclusion Criteria

Forty patients who had both a full-head NewTom 5G CBCT scan and a digital lateral cephalogram from Sirona Orthophos XG Plus were selected from the Loma Linda University Graduate Orthodontic Clinic patient database. The exclusion criteria included lateral cephalograms with significant overlap of first molars (defined as >2 mm), missing first molar(s), and significant overlap of the border of the mandible (defined as >2 mm) whether it be a physical asymmetry or positioning error. For the Sirona Orthophos XG Plus digital lateral cephalograms with minor first molar overlap or minor mandibular border overlap (defined as ≤2 mm), the NewTom 5G CBCT synthesized lateral cephalograms were adjusted to simulate the position in which the Sirona Orthophos XG Plus digital lateral cephalograms were taken. Linear and angular measurements including vertical and sagittal components were compared between the NewTom 5G CBCT synthesized lateral cephalograms in the perspective projection where the projection center was specified to the Porion location and the Sirona Orthophos XG Plus digital lateral cephalograms.

Statistical Analysis

The statistical analyses used in this study were performed by using IBM SPSS 21.0 (IBM Corp., Armonk, NY, USA) at $\alpha = 0.05$. The agreements among the digital caliper measurements of the washers versus the Sirona Orthophos XG Plus digital lateral cephalogram, the NewTom 5G CBCT synthesized lateral cephalogram in the orthogonal projection, and the NewTom 5G CBCT synthesized lateral cephalogram in the perspective projection were analyzed using Kruskal Wallis. Intraclass correlation coefficients tests were used to determine intraexaminer and interexaminer reliability. The measurements between the Sirona Orthophos XG Plus digital lateral cephalograms and the NewTom 5G CBCT synthesized lateral cephalograms were compared and analyzed using a paired-t test. Nonparametric tests were performed to adjust for measurements in which the data did not show a normal distribution.

RESULTS

Tables 2-9 show the comparison of means and standard deviations for all the washer measurements in the vertical and horizontal dimensions taken from the caliper, Sirona digital lateral cephalogram, NewTom synthesized lateral cephalogram in the orthogonal projection, and the NewTom synthesized lateral cephalogram in the perspective projection. The % magnifications between the caliper and the various imaging modalities are also displayed.

Table 2. Comparison of Mean ± Standard Deviation and Statistical (SD) % Magnification of Midline wire-grid Nasion washer measurements from different measurement modalities using Kruskal Wallis Test at α = 0.05.

	Mean ± SD (mm)	% Magnification
Vertical Measurement		
Caliper	9.55±.01	100^{a}
Sirona Orthophos XG Plus Vertical	9.63±.01	101^{a}
NewTom 5G CBCT Perspective Vertical	10.32±.06	108^{b}
NewTom 5G CBCT Orthogonal Vertical	9.28±.04	97^{c}
Horizontal Measurement		
Caliper	9.55±.01	100^{a}
Sirona Orthophos XG Plus Horizontal	9.75±.01	102^{b}
NewTom 5G CBCT Perspective Horizontal	9.85±.16	103^{b}
NewTom 5G CBCT Orthogonal Horizontal	9.00±.00	94^{c}

* ^{a,b,c} Different superscript letters denote statistical difference
*Vertical and horizontal measurements were analyzed separately

Table 3. Comparison of Mean ± Standard Deviation and Statistical (SD) % Magnification of Midline wire-grid A-point washer measurements from different measurement modalities using Kruskal Wallis Test at α = 0.05.

	Mean ± SD (mm)	% Magnification
Vertical Measurement		
Caliper	9.55±.01	100[a]
Sirona Orthophos XG Plus Vertical	9.63±.01	101[a]
NewTom 5G CBCT Perspective Vertical	10.29±.01	108[b]
NewTom 5G CBCT Orthogonal Vertical	9.26±.05	97[c]
Horizontal Measurement		
Caliper	9.55±.01	100[a]
Sirona Orthophos XG Plus Horizontal	9.75±.01	102[b]
NewTom 5G CBCT Perspective Horizontal	9.88±.15	103[b]
NewTom 5G CBCT Orthogonal Horizontal	9.00±.00	94[c]

* [a,b,c] Different superscript letters denote statistical difference
*Vertical and horizontal measurements were analyzed separately

Table 4. Comparison of Mean ± Standard Deviation and Statistical (SD) % Magnification of Midline wire-grid Pogonion washer measurements from different measurement modalities using Kruskal Wallis Test at α = 0.05.

	Mean ± SD (mm)	% Magnification
Vertical Measurement		
Caliper	9.55±.01	100[a]
Sirona Orthophos XG Plus Vertical	9.64±.00	101[a]
NewTom 5G CBCT Perspective Vertical	10.30±.08	108[b]
NewTom 5G CBCT Orthogonal Vertical	9.27±.00	97[c]
Horizontal Measurement		
Caliper	9.55±.01	100[a]
Sirona Orthophos XG Plus Horizontal	9.76±.01	102[b]
NewTom 5G CBCT Perspective Horizontal	9.82±.15	103[b]
NewTom 5G CBCT Orthogonal Horizontal	9.00±.00	94[c]

* [a,b,c] Different superscript letters denote statistical difference
*Vertical and horizontal measurements were analyzed separately

Table 5. Comparison of Mean ± Standard Deviation and Statistical (SD) % Magnification of Midline wire-grid Sella washer measurements from different measurement modalities using Kruskal Wallis Test at α = 0.05.

	Mean ± SD (mm)	% Magnification
Vertical Measurement		
Caliper	9.55±.01	100[a]
Sirona Orthophos XG Plus Vertical	9.64±.01	101[a]
NewTom 5G CBCT Perspective Vertical	10.33±.05	108[b]
NewTom 5G CBCT Orthogonal Vertical	9.24±.05	97[c]
Horizontal Measurement		
Caliper	9.55±.01	100[a]
Sirona Orthophos XG Plus Horizontal	9.48±.01	99[a]
NewTom 5G CBCT Perspective Horizontal	9.88±.15	103[b]
NewTom 5G CBCT Orthogonal Horizontal	9.00±.00	94[c]

* [a,b,c] Different superscript letters denote statistical difference
*Vertical and horizontal measurements were analyzed separately

Table 6. Comparison of Mean ± Standard Deviation and Statistical (SD) % Magnification of Midline wire-grid Basion washer measurements from different measurement modalities using Kruskal Wallis Test at α = 0.05.

	Mean ± SD (mm)	% Magnification
Vertical Measurement		
Caliper	9.55±.01	100[a]
Sirona Orthophos XG Plus Vertical	9.64±.01	101[a]
NewTom 5G CBCT Perspective Vertical	10.30±.12	108[b]
NewTom 5G CBCT Orthogonal Vertical	9.29±.07	97[c]
Horizontal Measurement		
Caliper	9.55±.01	100[a]
Sirona Orthophos XG Plus Horizontal	9.48±.01	99[a]
NewTom 5G CBCT Perspective Horizontal	9.88±.15	103[b]
NewTom 5G CBCT Orthogonal Horizontal	9.00±.00	94[c]

* [a,b,c] Different superscript letters denote statistical difference
*Vertical and horizontal measurements were analyzed separately

Table 7. Comparison of Mean ± Standard Deviation and Statistical (SD) % Magnification of Right wire-grid Porion washer measurements from different measurement modalities using Kruskal Wallis Test at α = 0.05.

	Mean ± SD (mm)	% Magnification
Vertical Measurement		
Caliper	11.35±.01	100[a]
Sirona Orthophos XG Plus Vertical	11.38±.00	100[a]
NewTom 5G CBCT Perspective Vertical	12.27±.08	108[b]
NewTom 5G CBCT Orthogonal Vertical	11.20±.05	99[a]
Horizontal Measurement		
Caliper	11.35±.01	100[a]
Sirona Orthophos XG Plus Horizontal	11.39±.01	100[a]
NewTom 5G CBCT Perspective Horizontal	12.18±.06	107[b]
NewTom 5G CBCT Orthogonal Horizontal	10.56±.08	93[c]

* [a,b,c] Different superscript letters denote statistical difference
*Vertical and horizontal measurements were analyzed separately

Table 8. Comparison of Mean ± Standard Deviation and Statistical (SD) % Magnification of Right wire-grid Molar washer measurements from different measurement modalities using Kruskal Wallis Test at α = 0.05.

	Mean ± SD (mm)	% Magnification
Vertical Measurement		
Caliper	11.35±.01	100[a]
Sirona Orthophos XG Plus Vertical	11.35±.00	100[a]
NewTom 5G CBCT Perspective Vertical	12.33±.08	109[a]
NewTom 5G CBCT Orthogonal Vertical	11.03±.05	97[c]
Horizontal Measurement		
Caliper	11.35±.01	100[a]
Sirona Orthophos XG Plus Horizontal	11.39±.01	100[a]
NewTom 5G CBCT Perspective Horizontal	12.19±.07	107[b]
NewTom 5G CBCT Orthogonal Horizontal	10.63±.09	94[c]

* [a,b,c] Different superscript letters denote statistical difference
*Vertical and horizontal measurements were analyzed separately

Table 9. Comparison of Mean ± Standard Deviation and Statistical (SD) % Magnification of Left wire-grid Porion washer measurements from different measurement modalities using Kruskal Wallis Test at α = 0.05.

	Mean ± SD (mm)	% Magnification
Vertical Measurement		
Caliper	11.15±.01	100[a]
Sirona Orthophos XG Plus Vertical	11.38±.01	102[b]
NewTom 5G CBCT Perspective Vertical	12.14±.05	109[c]
NewTom 5G CBCT Orthogonal Vertical	11.08±.13	99[a]
Horizontal Measurement		
Caliper	11.15±.01	100[a]
Sirona Orthophos XG Plus Horizontal	11.38±.01	102[b]
NewTom 5G CBCT Perspective Horizontal	12.17±.05	109[b]
NewTom 5G CBCT Orthogonal Horizontal	10.58±.06	95[c]

* [a,b,c] Different superscript letters denote statistical difference
*Vertical and horizontal measurements were analyzed separately

Table 10 shows that the vertical diameter millimeter measurement difference between the expected magnification and actual measured magnification in the perspective projection ranges from 0.07 mm to 0.19 mm. The vertical diameter millimeter difference between the caliper measurements and measurements in the orthogonal projection range from 0.07 mm to 0.31 mm.

Table 10. Calculated washer measurement difference in the vertical dimension.

	Caliper Measure -ment (mm)	NewTom 5G Orthogonal Projection (mm)	Sirona Orthophos XG Plus (mm)	NewTom 5G Perspective Projection (mm)	Expected Magnifica- tion 109.7% (mm)	Actual Calculated Magnifica- tion (%)	Difference between Expected Magnification and Actual Measured Magnification in the Perspective Projection (mm)	Difference between the Caliper Measurements and the Measurements in the Orthogonal Projection (mm)
Porion (R)	11.349	11.20	11.383	12.27	12.449	1.081	0.18	0.15
Molar (R)	11.349	11.03	11.347	12.33	12.449	1.086	0.12	0.32
Nasion	9.550	9.28	9.634	10.32	10.476	1.080	0.16	0.27
A-point	9.549	9.26	9.634	10.29	10.475	1.078	0.19	0.29
Pogonion	9.549	9.27	9.637	10.30	10.475	1.079	0.18	0.28
Sella	9.551	9.24	9.636	10.33	10.477	1.082	0.15	0.31
Basion	9.548	9.29	9.635	10.40	10.474	1.089	0.07	0.26
Porion (L)	11.152	11.08	11.376	12.14	12.233	1.089	0.09	0.07

Table 11 shows that the horizontal diameter millimeter measurement difference between the expected magnification and actual measured magnification in the perspective projection ranges from 0.06 mm to 0.66 mm. The horizontal diameter millimeter difference between the caliper measurements and measurements in the orthogonal projection range from 0.55 mm to 0.75 mm.

Table 11. Calculated washer measurement difference in the horizontal dimension.

	Caliper Measure -ment (mm)	NewTom 5G Orthogonal Projection (mm)	Sirona Orthophos XG Plus (mm)	NewTom 5G Perspective Projection (mm)	Expected Magnifica- tion 109.7% (mm)	Actual Calculated Magnifica- tion (%)	Difference between Expected Magnification and Actual Measured Magnification in the Perspective Projection (mm)	Difference between the Caliper Measurements and the Measurements in the Orthogonal Projection (mm)
Porion (R)	11.349	10.60	11.386	12.18	12.450	1.073	0.27	0.75
Molar (R)	11.349	10.60	11.391	12.19	12.450	1.074	0.26	0.75
Nasion	9.550	9.00	9.746	9.85	10.476	1.031	0.63	0.55
A-point	9.549	9.00	9.752	9.88	10.475	1.035	0.60	0.55
Pogonion	9.549	9.00	9.756	9.82	10.475	1.028	0.66	0.55
Sella	9.551	9.00	9.475	9.88	10.477	1.034	0.60	0.55
Basion	9.548	9.00	9.476	9.88	10.474	1.035	0.59	0.55
Porion (L)	11.152	10.6	11.379	12.17	12.234	1.091	0.06	0.55

High intraclass correlation coefficients indicate strong interexaminer and intraexaminer reliability for Rickets analysis measurements (Tables 12-13).

Table 12. Intraexaminer reliability.

	Intraclass Correlation Coefficient[b]	95% Confidence Interval	
		Lower Bound	Upper Bound
Single Measures	1.000[a]	.999	1.000
Average Measures	1.000	1.000	1.000

a. The estimator is the same, whether the interaction effect is present or not.

b. Type A intraclass correlation coefficients using an absolute agreement definition.

Table 13. Interexmainer reliability.

	Intraclass Correlation Coefficient[b]	95% Confidence Interval	
		Lower Bound	Upper Bound
Single Measures	.999[a]	.998	.999
Average Measures	.999	.999	1.000

a. The estimator is the same, whether the interaction effect is present or not.

b. Type A intraclass correlation coefficients using an absolute agreement definition.

Table 14 shows the comparison of linear measurements (mm) between the Sirona Orthophos XG Plus digital lateral cephalograms and the NewTom 5G CBCT synthesized lateral cephalograms in Group 1. Only Lower Lip to E-Plane measurements were not statistically significantly different (P = 0.139).

Table 14. Comparison of linear measurements (mm) between the two imaging modalities in Group 1 using paired t-test at α = 0.05.

Linear Measurement items	Sirona Orthophos XG Plus	NewTom 5G CBCT	Difference	95% Confidence Interval for Mean Difference		P-value
				Lower	Upper	
Convexity	3.05±3.21	3.40±3.48	-0.35±0.88	-0.63	-0.07	0.015*
Cranial Length	55.39±3.61	59.56±3.33	-4.17±1.83	-4.75	-3.58	0.001*
L1 Protrusion	2.86±3.10	3.21±3.36	-0.35±0.65	-0.56	-0.14	0.003*
Lower Lip to E-Plane	-0.55±3.16	-0.85±3.22	0.31±1.11	-0.05	0.66	0.139
U-Incisor Protrusion	6.83±3.70	7.65±3.87	-0.82±0.68	-1.04	-0.61	0.001*
U6-PT Vertical	17.03±3.77	18.00 ±4.38	-0.98±1.52	-1.47	-0.49	0.001*

*Statistically significant difference

Table 15 shows that for Group 1, the differences between the angular measurements from the two imaging modalities were statistically different (P < 0.05) for Ricketts facial-axis, lower face height, and mandibular arc.

Table 25. Comparison of angular measurements (°) between the two imaging modalities in Group 1 using paired t-test at α = 0.05.

Angular Measurement items	Sirona Orthophos XG Plus	NewTom 5G CBCT	Difference	95% Confidence Interval for Mean Difference		P-value
				Lower	Upper	
Cranial Deflection	28.08±2.12	28.04±1.79	0.04±1.39	-0.40	0.49	0.957
Facial Angle	88.43±3.42	88.14±3.62	0.30±1.18	0.08	0.67	0.126
Ricketts Facial Axis	89.49±4.16	88.48 ±3.98	1.01±1.57	0.50	1.51	0.001*
FMA (MP-FH)	26.02±4.64	26.16±4.68	-0.14±1.46	-0.61	0.32	0.697
Interincisal Angle	129.11±10.38	128.55±10.80	0.57±2.07	-0.10	1.23	0.130
L1 to A-Po	22.32±5.99	22.24±5.94	0.09±1.89	-0.52	0.69	0.955
Lower Face Height	45.38±4.26	46.79±6.71	-1.41±4.76	-2.93	0.11	0.027*
Mandibular Arc	31.34±4.93	32.41±4.69	-1.07±2.87	-1.99	-0.15	0.029*
Maxillary Depth	91.66±3.10	91.42±3.18	0.24±1.39	-0.20	0.68	0.340

*Statistically significant difference

Table 16 shows the comparison of linear measurements (mm) between the Sirona Orthophos XG Plus digital lateral cephalograms and the NewTom 5G CBCT synthesized lateral cephalograms in Group 2. Only Lower Lip to E-Plane measurements were not statistically significantly different (P = 0.077).

Table 26. Comparison of linear measurements (mm) between the two imaging modalities in Group 2 using paired t-test at α = 0.05.

Linear Measurement items	Sirona Orthophos XG Plus (mm)	NewTom 5G	Difference	95% Confidence Interval for Mean Difference		P-value
				Lower	Upper	
Convexity	2.82±2.77	3.18±3.10	-0.36±0.64	-0.56	-0.16	0.001*
Cranial Length	54.74±2.64	59.87±2.70	-5.13±1.81	-5.71	-4.54	0.001*
L1 Protrusion	2.76±2.85	3.06±3.14	-0.30±0.62	-0.50	-0.10	0.007*
Lower Lip to E-Plane	-0.49±3.19	-0.74±3.36	0.26±1.06	-0.08	0.60	0.077
U-Incisor Protrusion	6.08±3.30	6.96±3.79	-0.89±0.65	-1.10	-0.68	0.001*
U6-PT Vertical	16.28±3.53	17.88±3.65	-1.60±1.26	-1.99	-1.19	0.001*

*Statistically significant difference

Table 17 shows that for Group 2, the differences between the angular measurements from the two imaging modalities were statistically different ($P < 0.05$) for Ricketts facial-axis, interincisal angle, and lower face height.

Table 17. Comparison of angular measurements (°) between the two imaging modalities in Group 2 using paired t-test at $\alpha = 0.05$.

Angular Measure-ment items	Sirona Orthophos XG Plus	NewTom 5G	Difference	95% Confidence Interval for Mean Difference		P-value
				Lower	Upper	
Cranial Deflection	28.36±2.21	28.74±1.96	-0.38±1.41	-0.83	0.07	0.092
Facial Angle	88.59±3.17	88.68±3.13	-0.09±1.28	-0.50	0.32	0.712
Ricketts Facial Axis	89.01±3.30	88.49±3.16	0.52±1.36	0.08	0.95	0.020*
FMA (MP-FH)	26.22±3.43	26.10±3.36	0.12±1.15	-0.25	0.49	0.743
Interincisal Angle	131.03±12.20	130.53±12.02	0.50±1.57	-0.01	1.01	0.044*
L1 to A-Po	22.62±6.41	22.61±6.54	0.01±1.38	-0.43	0.45	0.883
Lower Face Height	45.19±3.72	45.70±3.65	-0.52±1.53	-1.00	-0.03	0.043*
Mandibular Arc	32.19±5.40	32.39±5.22	-0.21±2.33	-0.95	0.54	0.628
Maxillary Depth	91.59±2.89	91.76±2.76	-0.17±1.51	-0.65	0.32	0.506

*Statistically significant difference

CHAPTER FOUR

DISCUSSION

Currently, “normal values” for 3D measurements in cephalometric analyses remain undefined, and 3D normative values from people with normal occlusion is unlikely to be obtained due to high economic cost, high dose of exposure and ethical issues.[17] It is not known whether measurements of cephalometric analyses obtained from NewTom 5G CBCT synthesized lateral cephalograms can be compared with measurements of cephalometric analyses obtained from Sirona Orthophos XG Plus digital lateral cephalograms. The purpose of the study was to determine whether the NewTom 5G CBCT synthesized cephalograms of patients could provide the same measurement of Ricketts analyses as the Sirona Orthophos XG Plus digital lateral cephalogram.

The purpose of constructing the phantom and measuring the washers was to verify the expected 109.7% magnification of Sirona Orthophos XG Plus lateral cephalogram, the 109.7% magnification of the NewTom 5G CBCT synthesized lateral cephalogram in the perspective projection, and the 0% magnification of the NewTom 5G CBCT synthesized lateral cephalogram in the orthogonal projection. One would expect the measurements of the washers to be the same for the caliper measurements and measurements obtained from the NewTom 5G synthesized lateral cephalogram in the orthogonal view since the orthogonal projection is supposed to create 1:1 images. Although the results show a statistical difference in some of the measurements between the caliper measurements and the measurements in the orthogonal projection, this statistical difference is small. Measuring the vertical and horizontal dimensions of the washer yielding small numbers affected the small standard error whereas measuring the distance between washers thus allowing for a greater standard error could have provided more valuable data. The horizontal and vertical diameter measurements of the washers in the perspective projection were expected to show a 109.7% magnification when compared to the caliper measurements. In comparing the means of the horizontal and vertical measurements of the washers, the difference between the expected magnification of 109.7% and the actual calculated magnification in the perspective projection showed a range from 0.07 mm to 0.19 mm in the vertical measurements and a range from 0.06 mm to 0.66 mm in the horizontal measurements. In comparing the means of caliper measurements to that of the measurements in the orthogonal projection, the difference in the vertical measurements ranged from 0.07 mm to 0.32 mm and the difference in the horizontal measurements ranged from 0.55 mm to 0.75 mm. With the greatest difference being about three quarters of a mm, one can say there is a clinical significance. In order to compensate for these differences, adjustments should be made on the magnification factor on CBCT images to achieve measurements that are closer to the caliper or Sirona measurements. Therefore, it calls for reevaluation of the magnification factor used during tracing. The reference line used for calibrating magnification has to be recalibrated.

For Group 1 and Group 2, the NewTom 5G synthesized lateral cephalograms were created in the perspective projection because the distortion of perspective CBCT is intended to match that of conventional digital lateral cephalograms. The purpose of incorporating exclusion criteria in Group 2 as well as reorienting the 3D volumes to closely match the patient head position at the time the Sirona Orthophos XG Plus digital lateral cephalograms were obtained was to limit as much variability in cephalometric measurement as possible that would introduce error in comparing the precision of the 2 imaging modalities in this study.

For 2D lateral cephalogram imaging, patient positioning is critical in minimizing projection errors. Even with the aid of a cephalostat, the patient's head can be rotated thus leading to variation in cephalometric measurements. This error in conventional digital cephalometry can be eliminated with CBCT synthesized projections because the 3D volume can be reoriented. An advantage of having a 3D volume at the start of treatment followed by conventional lateral cephalograms for progress records is that the 3D volume can be reoriented to simulate the same head position with each successive progress digital lateral cephalogram thus minimizing measurement errors in comparing cephalometric analyses.

In both an in-vitro study performed on dry skulls and an in-vivo study it was demonstrated that cephalometric measurements performed on CBCT synthesized cephalograms are not clinically different from conventional cephalometric analyses.[7,8] The results of this study show that of the 15 cephalometric measurements in Group 1 and in Group 2, 3 angular measurements and 5 out of the 6 of the linear measurements were found to be statistically different between the two imaging modalities. The lower lip to E-plane was the only linear measurement that was not statistically different. It is important to note the confidence interval which shows that the lack of statistical difference was due to the fact that there were overlapping positive values and negative values of the lower lip to E-plane measurements. Furthermore, the statistical differences found in these measurements support the differences in magnification found in the washer diameter results in this study. When strictly comparing the means and standard deviations, the linear and angular measurements from Sirona Orthophos XG Plus lateral cephalograms and NewTom 5G CBCT synthesized lateral cephalograms are clinically comparable. However, there were several measurements that were statistically different and those cannot be ignored.

In both groups, the statistical differences found in the angular measurements do not translate into a clinical significance, however, the statistical differences found in the linear measurements relate to a clinical significance. For example, in Table 14 and 16, the mean and standard deviation of the difference between the Sirona and CBCT cranial length measurements were -4.17±1.83 and -5.13±1.81 for Group 1 and Group 2 respectively. One may argue that even though the mean difference is significant, because it is not a measurement frequently used in clinical diagnosis, that it is not critical. However, this difference translates to a clinical significance when superimposing Sirona Orthophos XG Plus digital lateral cephalograms to NewTom 5G synthesized lateral cephalograms. Although the means and standard deviations of linear and angular measurements are comparable between the two imaging modalities, it is likely that superimpositions will be difficult. Groups 1 and 2 show that the Sirona Orthophos XG Plus lateral cephalograms versus NewTom 5G CBCT synthesized lateral cephalograms at the current forms do not match well in the linear aspect, but match well in the angular aspect. Therefore, as mentioned previously, there is a need for reevaluation of the magnification factor used during tracing.

Calibrating the magnification factor between the Sirona Orthophos XG Plus digital lateral cephalograms and NewTom 5G synthesized lateral cephalograms would be beneficial in superimposing tracings and in reducing x-ray exposure by eliminating the need for a digital lateral cephalogram in addition to a CBCT image.

CHAPTER FIVE

CONCLUSIONS

1. There is a statistical difference in percent magnification of washer measurements in both the horizontal and vertical dimensions between the caliper measurements versus the various imaging modalities.
2. Ricketts cephalometric analysis measurements in NewTom 5G CBCT synthesized lateral cephalograms and Sirona Orthophos XG Plus digital lateral cephalograms are clinically comparable when looking strictly at the means and standard deviations of the measurements, which should not affect proper clinical diagnosis.
3. Ricketts cephalometric analysis measurements in NewTom 5G CBCT synthesized lateral cephalograms and Sirona Orthophos XG Plus digital lateral cephalograms are statistically different for all linear measurements excepting lower lip to E-plane and this translates to a clinical significance when superimpositions are needed.
4. It is likely that superimpositions will be difficult when superimposing Sirona Orthophos XG Plus digital lateral cephalograms to NewTom 5G synthesized lateral cephalograms.
5. In order for synthesized cephalometric images from NewTom 5G CBCT to be used to bridge the transition from 2D Sirona Orthophos XG Plus machine to NewTom 5G CBCT 3D image analysis, a new calibration for magnification is necessary.
6. Attempts should be made across the industry to standardize software to produce cephalometric images at a 1:1 ratio.

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