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Evaluating Dimensional Accuracy and Reliability of "Stitched" Small Field of View (SSFOV) Cone Beam Computed Tomography (CBCT) Datasets for Use in Proprietary Dental Implant Guided Surgery Software

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Evaluating Dimensional Accuracy and Reliability of "Stitched" Small Field of View (SSFOV) Cone Beam Computed Tomography (CBCT) Datasets for Use in Proprietary Dental Implant Guided Surgery Software

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Nicholas Luke Egbert D.D.S.
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ABSTRACT

Background: Recently a “stitched” small field of view (SSFOV) cone beam computed tomography (CBCT) extraoral imaging system (Kodak 9000D, Carestream Health Inc, Kodak Dental Systems, Marne-la-Vallee, France) has been released. The benefits of the 3D stitching module of stitched SFOV CBCT may include: broader range of applications, affordability, flexibility, safety optimizing radiation dose and improved workflow. With the reduced effective dose of radiation and cost to both the patient and clinician, this superior imaging modality becomes more accessible to the community, potentially elevating the standard of care. Currently, stitched data sets are restricted to diagnostic data gathering only. To date, no study has addressed the use of stitched SFOV CBCT data sets for import and use in the fabrication of image-guided CAD/CAM dental implant surgical stents. In comparison to conventional implant surgery, image-guided surgery provides safe, less-invasive treatment and superior planning ability and accuracy for the clinician.

Objective: The purpose of this study was to evaluate the dimensional accuracy and reliability of stitched SFOV CBCT reconstructed images for use in the fabrication of surgical dental implant guides.

Methods: Three 1.5 x 1.5 mm gutta percha points were fixated on the inferior border of a human mandible serving as control reference points. An additional ten, 1.5 x 1.5 mm gutta percha points, representing fiduciary markers of a proposed radiographic template, were then scattered on the buccal and lingual cortex at the level of the proposed complete denture flange. The distances between reference points and fiduciary markers were measured with digital calipers by providing an anatomic linear dimension (ALD). The mandible was the scanned, images reconstructed and “stitched” using manufacturer’s imaging software (Kodak 9000, Carestream Health Inc, Kodak Dental Systems, Marne-la-Vallee, France). The same measurements were accomplished within the CBCT software using the provided measuring tools and statistically evaluated for dimensional stability.

Results: In comparing the control (ALD) to the CBCT measurements, the mean difference between the ALD and SSFOV CBCT was found to be 0.34 mm with a 95% confidence interval of +0.24 to +0.44 and a mean standard deviation of 0.30. No systematic bias between the difference of the observations was evident. Thus, each measurement appeared to be as good as the other. The differences between the control and CBCT were acceptable within the defined parameters of this study.

Conclusions: Considering human error, this difference is considered clinically acceptable but should be accounted for when reading CBCT for diagnostic and or planning purposes. Proven accuracy of stitched SFOV CBCT data sets may allow image-guided implant surgical stents to be fabricated from such data sets.

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CHAPTER 1: INTRODUCTION AND BACKGROUND

The dental profession has entered a new age of radiographic diagnostic imaging (Guttenberg 2008). Subsequent to the reduction of effective dose radiation (Ludlow *et al.* 2003, 2006, 2008; Brooks 2008; Okano *et al.* 2008; Roberts *et al.* 2009) cost, size and image acquisition time, the use of Cone Beam Computed Tomography (CBCT) has increased significantly this past decade in the field of dentistry (Mozzo *et al.* 1998; Arai *et al.* 1999; Danforth *et al.* 2003; Sukovic 2003; Miles 2008; White and Pharoah 2008; Zoller and Neugebauer 2008). Conventional radiography produces distorted, magnified, superimposed grey-scale images that compromise visualization rendering pre-surgical diagnostic measurements subjective (Serman 1989). CBCT produces 3D virtual reconstructed and multi-planar reconstructed images including: cross-sectional (bucco-lingual), axial, coronal, sagittal and panoramic views (Scarfe and Farman 2008). Unparalleled submillimeter spatial resolution and geometric accuracy provides clinician's with solutions to diagnostic and surgical tasks improving the prognosis of future treatment (Sukovic 2003; Miles 2008).

Medical grade CT was initially used for dental applications in the late 1980's (Schwarz *et al.* 1989) and early 1990's (Garg and Vicari 1995). Many clinical applications of dental CBCT are found in the literature (Scarfe *et al.* 2006). Clinical applications include but are not limited to the following: complex 3rd molar surgery (Danforth *et al.* 2003; Susarla and Dodson 2007; Tantanapornkul *et al.* 2007; Flygare and Ohman 2008); minor oral surgery and orthognathic surgery (Nakagawa *et al.* 2002; Troulis *et al.* 2002; Alves *et al.* 2007; Caloss *et al.* 2007); orthodontic treatment, diagnosis and treatment planning (Maki *et al* 2003; Caprioglio *et al* 2007; Hechler 2008; Stratemann *et al.* 2008); assistance in complicated endodontic diagnosis and treatment (Patel *et al.* 2007, 2009; Patel 2009); visualizing and diagnosing temporomandibular joint disorders (Hilgers *et al.* 2005; Lewis *et al.* 2008) and sleep apnea (Strauss and Burgoyne 2008).

In a review of the literature by BouSerhal *et al.* (2002) researchers concluded many situations demand the use of cross-sectional imaging techniques for optimal preoperative planning of implant placement. Bone density and anatomic vital structures such as the inferior alveolar nerve and maxillary sinus may also be visualized, measured and anticipated prior to surgery (Aranyarachkul *et al.* 2005; Greenstein and Tarnow 2006; Lee *et al.* 2007). CBCT information may also be used to plan and construct stereolithographic and or CAD/CAM surgical stents increasing the accuracy of planned implant placement. If appropriate, the surgery may be performed flapless and may allow delivery of an immediate prefabricated prosthesis (Kraut 1998, Sarment *et al.* 2003; Perel and Triplett 2004; Balshi *et al.* 2006; Guerrero *et al.* 2006; Nikzad and Azari 2008; Jung *et al.* 2009; Valente *et al.* 2009; Ganeles, 2010; Ganz, 2010; Wilson, 2010). Using all available virtual tools, true restoratively driven implant dentistry can be accomplished via image-guided surgery, ultimately benefiting patients (Ganz 2008, 2010).

All aforementioned applications of CBCT technology assume the scan and subsequent reconstruction are dimensionally accurate and interpreted correctly by the clinician. Many studies are found in the literature verifying the dimensional accuracy of CBCT imaging; most of which using osteologic landmarks on dry human skulls as reference points for measurement (Lascala *et al.* 2004; Hilgers *et al.* 2005; Morishi *et al.* 2007; Lagrave *et al.* 2008; Loubele *et al.* 2008; Periago *et al.* 2008; Berco *et al.* 2009; Hassan *et al.* 2009; Moriera *et al.* 2009).

CHAPTER 2: REVIEW OF LITERATURE

Kobayashi and colleagues first (2004) evaluated the accuracy of images produced by a prototype limited cone-beam computed tomography (LCBCT) in comparison to spiral CT (SCT). The vertical distance from a reference point to the alveolar ridge was measured by caliper on 5 sliced cadaver mandibles, and the measurement values obtained from the CT images were accurately reproduced with a <2.2% error. More recently Loubele and colleagues (2008) placed gutta percha reference points on both sides of the alveolar ridge in a formalin-fixed human maxilla at known distances. Images were produced using CBCT (Accuitomo 3D; Morita, Kyoto, Japan) and MSCT (4-slice Somatom VolumeZoom and 16-slice Somatom Sensation 16; Siemens, Erlangen, Germany) and measured. Both CBCT and MSCT yielded submillimeter accuracy for linear measurements on an *ex vivo* specimen.

Few studies demonstrate inconsistencies in the dimensional accuracy of CBCT imaging and its associated software reconstruction. Lascala and colleagues (2004) made 13 measurements on 8 dry skulls with digital calipers which served as a control. CBCT images were obtained (NewTom 9000; Quantitative Radiology, Verona, Italy) measured on proprietary software and compared to the control measurements. It was found the CBCT underestimated the measurements as compared to the control near the skull base. Inconsistencies in the accuracy of the reconstructed DICOM files by a proprietary software program were reported by Periago and colleagues in the literature (2008). Control measurements were made with digital calipers of 23 cephalometric landmarks on 23 different human skulls. The authors concluded many linear measurements between cephalometric landmarks on 3D volumetric surface renderings obtained using Dolphin 3D software generated from CBCT datasets may be statistically, significantly different from anatomic dimensions.

Recent studies have been published regarding proper head positioning during scan acquisition. Berco *et al*. (2009) and Hassan *et al*. (2009) insist skull orientation during CBCT scanning does not affect the accuracy or the reliability of the measurements.

The Kodak 9000D (Carestream Health Inc, Kodak Dental Systems, Marne-la-Vallee, France) 3D stitching program is a new 3D acquisition mode that automatically combines two or three localized volumes to construct a larger, composite 3D image that is needed for a wider region of examination (80mm by 37mm). The exams are shot one after the other (2 or 3 acquisitions). The unit is automatically directed to the multiple areas of the jaw that need to be imaged. When all the exams are completed, the software combines the volumes and reconstructs them into one composite image. The benefits of the 3D stitching module are: broader range of applications, affordability, flexibility and safety optimizing radiation dose and improved workflow.

In an unpublished study Garladinne-Nethi and colleagues (2008) compared the accuracy and reliability of linear horizontal measurements made on reformatted panoramic images from stitched small field of view (SFOV), large field of view (FOV)

CBCT datasets and conventional digital panoramic images to the anatomical truth. They found linear measurements on panoramic images reconstructed from stitched small FOV images to be reliable and accurate. This study did not include vertical nor angular measurements whose accuracy is imperative to image-guided surgical treatment.

Kopp and Ottl (2010) most recently published in the Journal of Dentomaxillofacial Radiology attempting to verify the dimensional stability of the Kodak 9000 using endodontic files in select teeth. Distances were measured between reproducible points and found to be acceptable (vertical distances varied between 0.212 and 0.409 mm). The authors conclude: "further evaluation….for subsequent splint fabrication may yield promising results" (Kopp and Ottl 2010, 516).

Currently, Kodak (Dental Systems Group, Carestream Health Inc, Kodak Dental Systems, Marne-la-Vallee, France) approved the use of stitched SFOV reconstructed data sets for the fabrication of implant surgical guides (Dual Scan 9000 Protocol, 2010). However, no scientific study has proven or disproven its application for surgical guides. The purpose of this study is to evaluate the accuracy and reliability of linear and angular measurements of gutt percha reference points and fiduciary markers, similar to those used in radiographic templates, with the Kodak 9000 CBCT stitching software. This may validate the use of stitched volumetric data sets in fabrication of stereolithographic and CAD/CAM surgical guides.

CHAPTER 3: MATERIALS AND METHODS

A single dentate dry human mandible, free of outstanding defects, was acquired for the study. Three 1.5 mm by 1.5 mm gutta percha (Henry Schein, Melville NY) reference points were then placed along the mid-crest of the inferior border of the mandible fixed with cyanoacrylate. These three points coincided with proposed “center” of the three localized spherical volumes recorded by the Kodak 9000D (Dental Systems Group, Carestream Health Inc, Kodak Dental Systems, Marne-la-Vallee, France). The first gutta percha reference point was placed on the lower right inferior border of the mandible inferior to the 1st molar #30. The second reference point was placed on the inferior border, mid-symphysis. The third reference point was fixated on the inferior border of the mandible inferior to the 1st molar #19. This positioning allowed for stable, accessible landmarks from which to measure with both digital calipers and in the reconstructed SSFOV CBCT renderings.

An additional ten, staggered, 1.5 mm x 1.5 mm gutta percha (Henry Schein, Melville NY) markers were placed in similar fashion at bone level. These markers represented fiduciary markers of a radiographic template preparatory for scanning and import into a proprietary guided surgery application. Markers were placed on each side of the mandible, five buccal and five lingual. This ensured 1 reference point and at least three fiduciary markers appear in each of the three localized spherical volumes. Using a myostatic outline, care was taken to place markers within the proper superio-inferior position coinciding with the proposed flanges of a radiographic template (Figure 3-1).

Control measurements were made using precision sliding digital calipers (General Tools, New York, NY) from the inferior, external center of reference point to reference point and each reference point to external center surface of all 10 fiduciary markers. Inter-reference point measurements were also made.

Control measurements using precision sliding digital calipers were recorded beginning with the lower right reference point. This point was designated reference point A for simplicity. The reference point found mid-symphysis was designated reference point B. The reference point in the lower left quadrant was designated reference point C. The fiduciary markers were labeled 1-10 beginning with the buccal lower right quadrant numbering sequentially, in counter-clockwise fashion, all buccal markers then lingual. Measurements were taken three times on three different days by the primary researcher. Data was compiled using a Microsoft Excel spreadsheet. The mean of the three measurements became the “anatomic linear dimension” (ALD) (Figure 3-1).

The mandible was then positioned on a calibration table in the Kodak 9000D (Carestream Health Inc, Kodak Dental Systems, Marne-la-Vallee, France). A 1.5 inch foam pad with a 0.5 mm thickness Biocryl (Great Lakes Orthodontics, Tonawanda, NY) separated the mandible from the calibration table and the foam as to not distort the visualization of the reference points by the calibration table or foam once scanned and reconstructed. The mandible was positioned with the aid of laser lights with the inferior

Figure 3-1. Control Measurement (ALD).

border of the mandible parallel with the horizontal plane and the mid-sagital plane aligned perpendicular to the horizontal plane. This altered positioning, inferior border versus the occlusal plane being parallel to the horizontal plane, allows for the capture of the entire mandible and all associated reference points despite the SFOV (37mm) and will not affect scanning accuracy per Berco *et al.* (2009) and Hassan *et al.* (2009). The scan was performed with the following reduced exposure settings: mA 6, KvP 80, 0.018 s and 0.2 Voxels (resolution), accounting for the lack of soft tissue density.

The scan was taken with care as to not move the mandible from its' position while scanning all three volumes. Images were acquired with a charged coupled device (CCD) sensor (Kodak RVG 6100). The raw DICOM data was stitched into a composite 3D rendering using the latest version of the Kodak 9000 proprietary software (KDIS v. 6.11.6.2 and 3D module v. 2.1). Multiplanar reconstruction (sagital, para-sagital, axial and coronal) slices were correctly manipulated and used to visualize and measure the linear and or angular distances from the three reference markers to each of the ten fiduciary markers with the software measuring tool. The images were viewed on a 19 inch monitor in default resolution (Dell, 1600 x 1200 pixels; 60 Hz; 200cdm, 300:1 contrast; 25 ms reaction time). The points and markers were visually located and marked with a 1000 dpi mouse (Dell).

Similar to the control, measurements were made from the inferior, center of the reference points to the center, external surface of the fiduciary markers. Care was taken to correctly adjust each slice in multi-planar reconstruction (MPR) view, identifying the most superficial aspect of each marker possible mimicking the control measurements made with the calipers (Figures 3-2 and 3-3). Measurements were made three times on three different days and logged into the spread-sheet. The mean was calculated for each measurement and considered the stitched small field of view CBCT dimension (SSFOV CBCT).

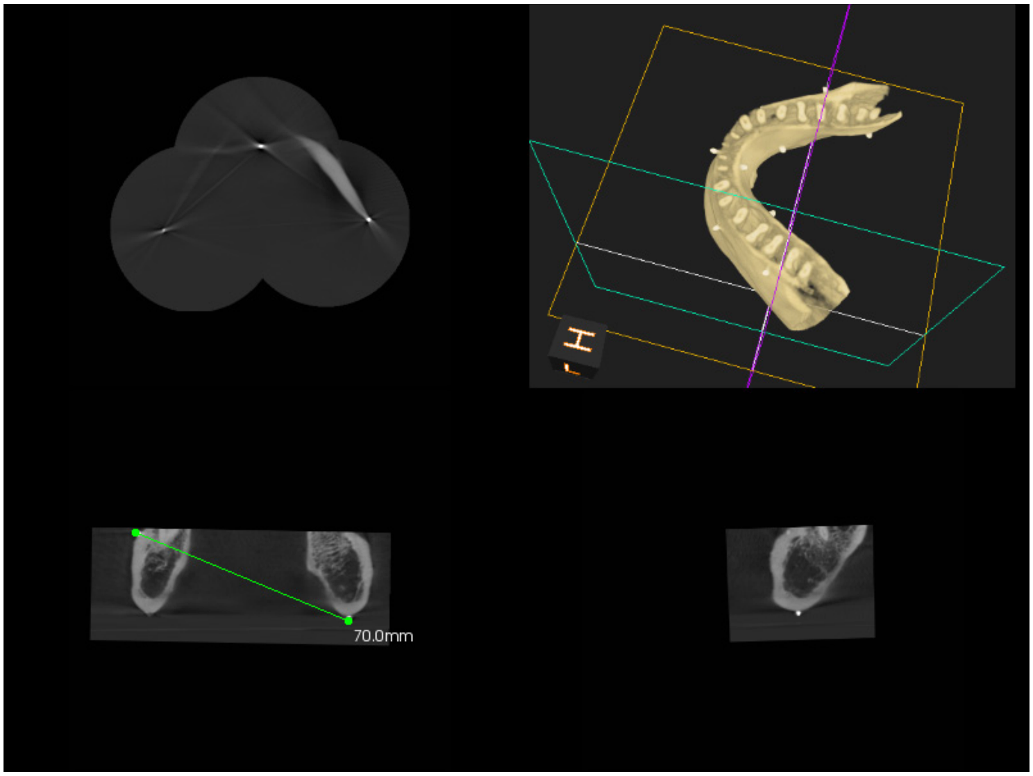

Figure 3-2. Reconstructed Stitched Small Field of View.

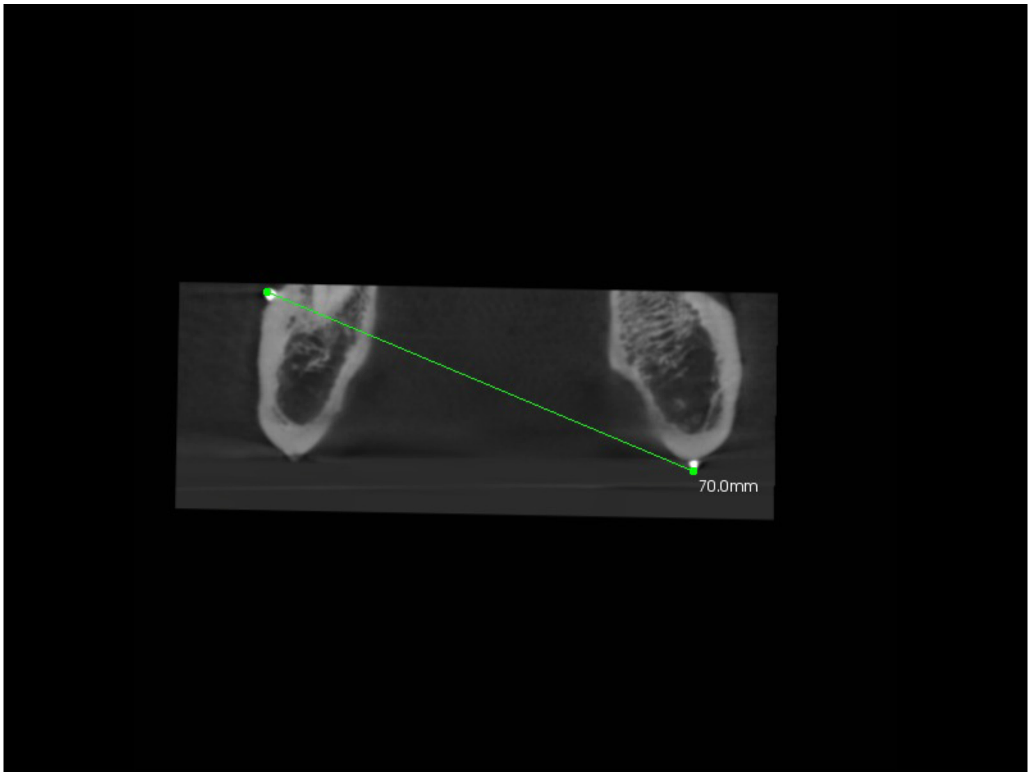

Figure 3-3. Measurement in Frontal Plane of Reconstructed SSFOV.

CHAPTER 4: RESULTS

Intra-operator control groups (ALD) and study group measurements (SSFOV CBCT) were tabulated for each of the three series of measurements taken for each groups (Appendix). The mean ALD was calculated for each of the three measurements (Table 4-1). The mean SSFOV CBCT was also calculated for each of the three measurements to allow analysis between the two groups (Table 4-2).

The means of the two groups were compared and the difference was determined between the groups by the mean SSFOV CBCT measurements from the control group (ALD). The overall mean difference between the control (ALD) and SSFOV CBCT measurements was 0.34 mm. The mean standard deviation between the two groups was 0.30 with a 95% confidence interval of ±0.102 (0.24 to 0.44).

Intra-operator, control measurements made on the skull with digital calipers (ALD) were analyzed and found to be statistically significantly different. This is attributed to the small 0.10 mm standard deviation in differences between measurements. The mean difference between control measurements was -0.01 mm 95% confidence interval bound of -0.04 to -0.03 (Table 4-1) with a standard deviation of 0.10. Sharp digital calipers and sharp gutta percha appoints facilitated accurate measurement of fiducial markers and reference points. Although statistically significantly different, mean differences of hundredths of a millimeter are not clinically relevant.

Differences in intra-operator CBCT digital measurements, were also found to be statistically, significantly different. The average mean difference between intra-operator CBCT measurements was -0.08 mm with a 95% confidence interval of -0.12 to -0.03 (Table 4-2). The statistical significance of these measurements is also due to the small 0.14 mm standard deviation in differences between measurements. This phenomenon may be explained due to controlled, predictable detection of the center of each gutta-percha marker on the mandible by manipulating multiple sub-millimeter planes viewed in the SSFOV CBCT software. The points were detected as a result of their radiopacity in each plane. Multiplanar views were manipulated until a slight, “pin-point” radiopacity was detected facilitating finding the center of each point. Despite the statistical analysis, a mean difference of -0.08 with a standard deviation of 0.14 mm is not clinically significant.

In comparing the control (ALD) to the CBCT measurements, the mean difference between the ALD and SSFOV CBCT was found to be 0.34 mm with a 95% confidence interval of +0.24 to +0.44 and a mean standard deviation of 0.30 (Table 4-3). No systematic bias between the difference of the observations. Thus, each measurement appeared to be as good as the other. The differences between the control and CBCT were acceptable within the defined parameters of this study.

Table 4-1. Statistical Analysis of Intra-Operator ALD (Control) Measurements.

ALD (CONTROL)	Δ (obs1-obs2)	Δ (obs1-obs3)	Δ (obs2-obs3)	Mean
Overall Mean	-0.01	-0.01	0.00	-0.01
Overall Standard Deviation	0.18	0.15	0.14	0.10
95% Confidence Interval	(-0.07 to -0.06)	(-0.06 to 0.04)	(-0.05 to -0.04)	(-0.04 to 0.03)

Notes: ALD = Anatomic Linear Dimension, **Δ** = Change between Measurements, obs = Observation Group.

Table 4-2. Statistical Analysis of Intra-Operator SSFOV CBCT Measurements.

SSFOV CBCT	Δ (obs1-obs2)	Δ (obs1-obs3)	Δ (obs2-obs3)	Mean
Overall Mean	-0.11	-0.12	-0.01	-0.08
Overall Standard Deviation	0.21	0.21	0.19	0.14
95% Confidence Interval	(-0.18 to -0.04)	(-0.19 to -0.04)	(-0.07 to 0.06)	(-0.12 to -0.03)

Notes: SSFOV = Stitched Small Field of View, CBCT = Cone Beam Computed Tomography, **Δ** = Change between Measurements, obs = Observation Group.

Table 4-3. Statistical Analysis between Groups.

Mean Difference	(ALD - SSFOV CBCT)
Overall Mean Difference	0.34
Overall Standard Deviation	0.3
95% Confidence Interval	(0.24 to 0.44)

Notes: ALD = Anatomic Linear Dimension, SSFOV = Stitched Small Field of View CBCT = Cone Beam Computed Tomography.

CHAPTER 5: DISCUSSION

A mean difference of 0.34 mm between the ALD and SSFOV CBCT measurements was found. As found in previous studies, it appears as though the CBCT data, or the interpretation thereof, may be dimensionally underestimated (Table 4-3).

Few studies demonstrate inconsistencies in the dimensional accuracy of CBCT imaging and its associated software reconstruction. Lascala and colleagues (2004) made 13 measurements on 8 dry skulls with digital calipers which served as a control. CBCT images were obtained (NewTom 9000; Quantitative Radiology, Verona, Italy) measured on proprietary software and compared to the control measurements. It was found the CBCT underestimated the measurements as compared to the control near the skull base. Inconsistencies in the accuracy of the reconstructed DICOM files by a proprietary software program were reported by Periago and colleagues in the literature (2008). Control measurements were made with digital calipers of 23 cephalometric landmarks on 23 different human skulls. The authors concluded many linear measurements between cephalometric landmarks on 3D volumetric surface renderings obtained using Dolphin 3D software generated from CBCT datasets may be statistically, significantly different from anatomic dimensions. Whether or not these measurements are clinically significant is a matter of defining the parameters for clinical significance.

A 1mm margin of error was considered the threshold for accuracy in this study. A 1mm margin of error was chosen due to its common application and use in nearly all clinical dental procedures. Parameters for restorative dental procedures are evaluated and executed in millimeter scale. To ensure successful treatment it is proposed the root canal space be properly instrumented and obturated within 1 mm of the root's apex. Probe depths are used to diagnose and treat the periodontium are used and visualized in a millimeter scale. More pertinent to this study, a 2mm "safety" zone near vital structures has been suggested when surgically planning and placing dental implants near vital structures (Greenstein and Tarnow 2006). This suggestion was based on conventional radiography with its' inherent distortions mentioned previously. Discrepancies greater than 1mm, with additional statistical margins of error, may encroach on these clinically accepted safety parameters.

Despite SSFOV CBCT's superior image accuracy, due to the operators visual and tactile limitations, it may not be prudent to assume one can approximate vital structures during surgical procedures with closer proximity than previously recommended in the literature.

According the results of this study, the likelihood of measurement discrepancies are likely to occur when using both analog measuring instruments (*i.e.*, calipers, probes etc.) and with digital SSFOV CBCT measurements. This increases the need for the accurate conversion of SSFOV CBCT images to CAD/CAM guides allowing for the safest surgery possible.

As noted previously, both the ALD and SSFOV CBCT differences were statistically significantly different yet clinically insignificant due to the sub-millimeter resolution of the measurements. This difference is beyond the resolution of the human eye and hand as noted above with the control measurements.

Measurement differences between control (AT) and stitched SFOV CBCT reconstructed images may allow image-guided implant surgical stents to be fabricated from such data sets. As recommended by Kopp and Ottl (2010) verification of the stitched rendering by measuring between two reference points in the scan and on the template may be judicious.

In dual scan, guided surgical protocols, landmarks such as definitive reference points or notches simply made with a round bur mid-symphysis and near the posterior borders of the radiographic template outside the positional osteotomy sites, would provide reference points in each of the three fields of view. These markers may be verified in the reconstructed image with digital measurements in the multi-planar views of the CBCT image. If the measurements are coincidental the operated should feel confident of the SSFOV. If significant discrepancies in measurement occur, the scan or stitched volumes may be inaccurate and cause the subsequent guide to be inaccurate. If this occurs, the guided surgery may be aborted.

These reference landmarks should also be measured and analyzed for potential dimensional changes during the fabrication of the subsequent implant surgical stent. cross-arch on radiographic template incorporating template landmarks for measurement verification of the subsequent guide. If a discrepancy is found the accuracy of the guide must be assumed inaccurate. Any inaccuracies found at this stage may be at the mercy of the guide fabrication process. Further studies may be needed to verify the accuracy of the guide fabrication process with the supplied DICOM files.

CHAPTER 6: CONCLUSIONS

In conclusion, the stitched composite 3D images appear accurate and reliable for diagnostic purposes within the operator’s physical limitations and parameters defined in this study. Clinically insignificant differences found between the control measurements and those of the stitched data sets may be taken into consideration when diagnosing and treatment planning both surgical and non-surgical dental procedures.

This minuscule difference may allow image-guided implant surgical stents to be fabricated from such data sets but not without difficulty. Comparing measurements between landmarks in each of the three spherical columns of the radiographic template with the corresponding markers seen in the reconstructed stitched SSFOV CBCT scan, and once again in the surgical guide, may alert the clinician of an inaccurate image reconstruction or template fabrication. If a discrepancy is found, the guide must be assumed inaccurate. Any inaccuracies found at this stage may be at the mercy of the guide fabrication process. Further studies may be needed to verify the accuracy of the guide fabrication process with the supplied DICOM files.

Despite stitched SFOV CBCT’s superior image accuracy, due to the operators’ visual and tactile limitations, it may not be prudent to assume one can approximate vital structures during surgical procedures with closer proximity than previously recommended in the literature.

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APPENDIX: SUMMARY OF MEASUREMENTS

Table A-1. Summary of Control (ALD) Measurements.

ALD Control	C1	C2	C3	Δ1v2	Δ1v3	Δ2v3	ΔAvg	Mean	SD
A-B	39.48	39.57	39.55	-0.09	-0.07	0.02	-0.05	39.53	0.04
B-C	39.67	39.75	39.61	-0.08	0.06	0.14	0.04	39.68	0.06
A-C	62.88	62.78	62.81	0.10	0.07	-0.03	0.05	62.82	0.04
A-1	26.6	26.32	26.49	0.28	0.11	-0.17	0.07	26.47	0.12
A-2	30.62	30.46	30.64	0.16	-0.02	-0.18	-0.01	30.57	0.08
A-3	51.4	51.43	51.57	-0.03	-0.17	-0.14	-0.11	51.47	0.07
A-4	60.77	60.94	60.89	-0.17	-0.12	0.05	-0.08	60.87	0.07
A-5	70.22	70.01	70.1	0.21	0.12	-0.09	0.08	70.11	0.09
A-6	60.14	59.8	60.06	0.34	0.08	-0.26	0.05	60	0.15
A-7	48.63	48.69	48.77	-0.06	-0.14	-0.08	-0.09	48.70	0.06
A-8	46.17	46.13	46.08	0.04	0.09	0.05	0.06	46.13	0.04
A-9	31.12	31.34	31.38	-0.22	-0.26	-0.04	-0.17	31.28	0.11
A-10	25.55	25.62	25.61	-0.07	-0.06	0.01	-0.04	25.59	0.03
B-1	47.74	47.63	47.58	0.11	0.16	0.05	0.11	47.65	0.07
B-2	30.79	30.8	30.84	-0.01	-0.05	-0.04	-0.03	30.81	0.02
B-3	26.07	26.01	26.02	0.06	0.05	-0.01	0.03	26.03	0.03
B-4	28.54	28.64	28.64	-0.10	-0.10	0.00	-0.07	28.61	0.05
B-5	46.74	47.08	47.09	-0.34	-0.35	-0.01	-0.23	46.97	0.16
B-6	49.04	48.9	48.73	0.14	0.31	0.17	0.21	48.89	0.13
B-7	29.23	29.81	29.32	-0.58	-0.09	0.49	-0.06	29.45	0.25
B-8	25.58	25.4	25.51	0.18	0.07	-0.11	0.05	25.50	0.07
B-9	25.92	26.1	25.82	-0.18	0.10	0.28	0.07	25.95	0.12
B-10	50.06	50.09	50.11	-0.03	-0.05	-0.02	-0.03	50.09	0.02

Table A-1. *Continued.*

ALD Control	C1	C2	C3	Δ1v2	Δ1v3	Δ2v3	ΔAvg	Mean	SD
C-1	70.84	70.9	70.9	-0.06	-0.06	0.00	-0.04	70.88	0.03
C-2	62.32	62.43	62.59	-0.11	-0.27	-0.16	-0.18	62.45	0.11
C-3	51.25	51.39	51.41	-0.14	-0.16	-0.02	-0.11	51.35	0.07
C-4	30.78	30.74	30.77	0.04	0.01	-0.03	0.01	30.76	0.02
C-5	26.32	26.33	26.34	-0.01	-0.02	-0.01	-0.01	26.33	0.01
C-6	26.92	26.83	26.67	0.09	0.25	0.16	0.17	26.81	0.10
C-7	30.02	29.97	29.99	0.05	0.03	-0.02	0.02	29.99	0.02
C-8	43.5	43.52	43.6	-0.02	-0.10	-0.08	-0.07	43.54	0.04
C-9	47.07	46.77	46.83	0.30	0.24	-0.06	0.16	46.89	0.13
C-10	61.58	61.55	61.54	0.03	0.04	0.01	0.03	61.56	0.02

Table A-2. Summary of CBCT Measurements.

V: CBCT	CBC1	CBC2	CBC3	Δ1v2	Δ1v3	Δ2v3	ΔAvg	Mean	SD
A-B	38.8	39.1	39	-0.30	-0.20	0.10	-0.13	38.97	0.15
B-C	39.6	39.9	39.8	-0.30	-0.20	0.10	-0.13	39.77	0.15
A-C	61.9	62	62.1	-0.10	-0.20	-0.10	-0.13	62	0.10
A-1	26.3	26.5	26.1	-0.20	0.20	0.40	0.13	26.3	0.20
A-2	30.2	30.1	30.2	0.10	0.00	-0.10	0.00	30.17	0.06
A-3	50.5	50.4	50.8	0.10	-0.30	-0.40	-0.20	50.57	0.21
A-4	60.4	60.7	60.9	-0.30	-0.50	-0.20	-0.33	60.67	0.25
A-5	69.1	69.5	69.3	-0.40	-0.20	0.20	-0.13	69.3	0.20
A-6	59	59.4	59.4	-0.40	-0.40	0.00	-0.27	59.27	0.23
A-7	47.9	47.8	48.2	0.10	-0.30	-0.40	-0.20	47.97	0.21
A-8	45.5	46	45.8	-0.50	-0.30	0.20	-0.20	45.77	0.25
A-9	30.7	31	31.1	-0.30	-0.40	-0.10	-0.27	30.93	0.21
A-10	25.4	25.6	25.4	-0.20	0.00	0.20	0.00	25.47	0.12
B-1	47	47.3	46.9	-0.30	0.10	0.40	0.07	47.07	0.21
B-2	30.7	30.8	30.8	-0.10	-0.10	0.00	-0.07	30.77	0.06
B-3	26.1	26	26.3	0.10	-0.20	-0.30	-0.13	26.13	0.15
B-4	28.9	28.9	28.8	0.00	0.10	0.10	0.07	28.87	0.06
B-5	47.4	47	47.1	0.40	0.30	-0.10	0.20	47.17	0.21
B-6	48.4	48.5	48.4	-0.10	0.00	0.10	0.00	48.43	0.06
B-7	29.7	29.5	29.4	0.20	0.30	0.10	0.20	29.53	0.15
B-8	25	25.2	25.1	-0.20	-0.10	0.10	-0.07	25.1	0.10
B-9	25.5	25.3	25.2	0.20	0.30	0.10	0.20	25.33	0.15
B-10	49.6	49.6	49.9	0.00	-0.30	-0.30	-0.20	49.7	0.17
C-1	70	70.2	70.1	-0.20	-0.10	0.10	-0.07	70.1	0.10
C-2	62.1	62.1	62.3	0.00	-0.20	-0.20	-0.13	62.17	0.12
C-3	51.1	51.3	51.2	-0.20	-0.10	0.10	-0.07	51.2	0.10
C-4	30.4	30.3	30.4	0.10	0.00	-0.10	0.00	30.37	0.06
C-5	26	26.1	26.1	-0.10	-0.10	0.00	-0.07	26.07	0.06

Table A-2. *Continued.*

V: CBCT	**CBC1**	**CBC2**	**CBC3**	**Δ1v2**	**Δ1v3**	**Δ2v3**	**ΔAvg**	**Mean**	**SD**
C-6	26.2	26.6	26.7	-0.40	-0.50	-0.10	-0.33	26.5	0.26
C-7	29.7	29.7	29.9	0.00	-0.20	-0.20	-0.13	29.77	0.12
C-8	43.2	43.3	43.2	-0.10	0.00	0.10	0.00	43.23	0.06
C-9	46.5	46.4	46.5	0.10	0.00	-0.10	0.00	46.47	0.06
C-10	61.2	61.4	61.4	-0.20	-0.20	0.00	-0.13	61.33	0.12

VITA

Dr. Nicholas Egbert was born in 1979. He received his Bachelors of Science in Medical Biology from the University of Utah in Salt Lake City, Utah in 2004. He then completed his Doctor of Dental Surgery from Creighton University, Omaha, Nebraska in 2004. He was accepted into the Advanced Prosthodontics Program at the University of Tennessee Health Science Center in 2008. Dr. Egbert is currently a third year resident, specializing in fixed and removable prosthodontics and surgical implant dentistry at UTHSC. He will be finishing his Master of Dental Science degree from the University of Tennessee. He is a current member of the American College of Prosthodontists (ACP) and eligible to challenge the board of examiners to become a Fellow of the ACP.