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Date: June 13, 2007

IMAGE DISTORTION AND SPATIAL RESOLUTION OF A COMMERCIALLY AVAILABLE CBCT

by

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Submitted in partial fulfillment of the requirements for the degree of Master of Science in Dentistry

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January 18, 2008

IMAGE DISTORTION AND SPATIAL RESOLUTION OF A COMMERCIALLY AVAILABLE CBCT

Abstract

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The purpose of this study was to evaluate images produced by CBCT for measurement distortion and spatial resolution. Phantoms were specially constructed for scanning in the CBCT machine. A specially designed phantom fabricated at the Craniofacial Imaging Center of the Case Western Reserve School of Dental Medicine (CIC-phantom) was used as an aid for analyzing distortion. It contained 0.3 mm diameter chromium metal markers approximately 5 mm apart in three planes of space. This phantom was scanned in the CBCT machine at each of the twelve possible settings at a commercial dental imaging center. The distance between the markers was measured three times using a DICOM viewer and three times directly with fine-tipped digital calipers. A line pair phantom, called the C-phantom, was also utilized to evaluate image resolution. Thirty evaluators were asked to analyze the

images and assigned a resolution value according to the separation of the line pairs. An analysis of the data revealed no statistically significant differences between measurements utilizing any of the image settings, in any dimension, or in the periphery compared to the center of the field of view. A side-by-side comparison of the CBCT measurements to the direct digital caliper measurements showed a statistically significant difference ($p < 0.01$), but not a clinically significant difference (< 0.1 mm). Image resolution variation was determined to be largely the result of voxel size and scan time. It was concluded that CBCT images had clinically accurate measurements in all parts of the image and at all machine settings. Smaller voxel sizes and longer scan times produced higher resolution images.

DEDICATION

This thesis is dedicated to my family. My father James, mother Alexis, and brother James have all been a source of guidance and support for me throughout my education. I sincerely appreciate their unending love and I am grateful for all the hard work and dedication they have put forth to get me to where I am today. I love you all more than could ever be expressed in words.

ACKNOWLEDGEMENTS

I wish to thank all the members of my thesis committee; Drs. J. Martin Palomo, Mark Hans, Edward Ruch, and B. Douglas Amberman. Your continual support and guidance is greatly appreciated.

I would like to extend my gratitude to Dr. Palomo. Your patient help and wonderful sense of humor helped me greatly in this process. You are an excellent orthodontist and teacher who has become a great friend.

Thank you Dr. Ruch for all of your time and dedication to my project. You literally opened your door to a stranger and gave up a lot of your time. I cannot thank you enough for that.

Thank you Dr. Amberman for reading over all the drafts of this thesis. You have been a great teacher to me in my orthodontic education. Your support and input for my project is greatly appreciated.

Thank you Dr. Hans for not only accepting me in the program, but for being an excellent teacher. Your sense of humor made me laugh many times and your dedication to

the Department has truly made Case Orthodontics a world class program.

Thank you to John Newland of Toothpics. Your knowledge helped to guide me through this project. I sincerely appreciate all of your ideas when I was gathering my scans and for your thought-provoking conversations.

Clifford Lowdenback, your help and friendship guided me through my first year of residency. I was lucky to have such a great "big brother" in the program.

Reid Wenger, your friendship and sense of humor mean a lot to me. I want to thank you for all of your help with my thesis project.

Kurt Kacer, your friendship and support was greatly appreciated. You are going to become an excellent orthodontist.

Thank you to my friends in the residency: Boyd Martin, Jeff Kwong, Jed Hildebrand, Eric Hughes, and Austin Phoenix. You all helped to brighten up my days and were a huge support in all the difficult times.

Thank you to Dr. Mark Schluchter. I appreciate your time and assistance in planning my statistical methods.

Thank you to Sebastian Baumgartel. Your help with my measurements and statistics is greatly appreciated.

A special thank you to Linda Hopp. Your support and understanding throughout this process was remarkable. You helped to put a smile on my face and gave me many cheerful days. I am very lucky to have you in my life

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LITERATURE REVIEW

Two-dimensional images commonly used in orthodontics include cephalograms and panoramic radiographs which are subject to geometric, rotational, and head positioning errors that can lead to the area of interest being misrepresented (Harrell et al. 2006). Accurate three-dimensional representations of dentofacial structures could help eliminate this problem and might provide additional diagnostic information. Three-dimensional representations of dental structures have been used for many years in the form of dental casts. Dental casts are a three-dimensional representation of the teeth and their interrelationships which are valuable for diagnosis and treatment planning. In a study conducted at the University of Michigan, fifty-seven orthodontic patients had full records taken including study models, facial photographs, a panoramic radiograph, and a lateral cephalogram with tracing. The records were presented to five part-time faculty members and who also had private practices. Starting with the study models first, sequential records were added; facial photographs,

the panoramic radiograph, the lateral cephalogram, and finally the tracing of the lateral cephalogram. The impact of each component of the orthodontic record on the treatment plan was analyzed. In 55% of orthodontic cases, study models alone provided adequate information and incremental addition of information from other types of diagnostic records made small differences (Han et al. 1991). The difficulty with this study was that in all cases the study model was presented first. There is the possibility that a change in the order of presentation might produce a different result. In fact, the authors realized this and stated that the order of the records could be varied, and for those orthodontists who rely on cephalometric analysis, the lateral cephalogram and tracing may be used as the first record instead of the study models (Han et al. 1991). In addition, the 55% of cases represent little more than half of all the treatment plans. This indicates that, while the three-dimensional records (the study models) helped for about half of the treatment plans, the other half could not be represented by the teeth alone.

The radiation exposure for three-dimensional imaging is increased over traditional panoramic radiography, but is still significantly less than medical CT scanners. Mah et al. (2003) has reported that radiation from cone beam computed tomography (CBCT) is one-fifth that of medical CT scanners and the radiation absorbed from a full mouth periapical series with D-speed film is approximately equivalent to a CBCT examination. Ludlow et al. (2003) examined the difference in radiation dose between CBCT and a direct digital panoramic unit and found that there was three to seven times more of a radiation dose from the CBCT. In a recent study, three different CBCT machines were compared to assess the radiation dose. Radiation exposure for the NewTom 3G™, i-CAT™, and CB MercuRay™, compared to panoramic radiography, ranged from four to forty-two times greater. However, it was clearly stated in this paper that the field of view, mA settings, and kV settings all influenced the radiation exposure more than the different machines (Ludlow et al. 2006).

CBCT technology can be used in the orthodontic practice to aid in the process of diagnosis and treatment planning. The three-dimensional volumes can be

reconstructed into traditional radiographic views. The interesting point about the reconstructed radiographic views is that they are orthographic projections. This means that the sizes of objects are independent of the distance of the object from the screen and that all lines remain parallel. Size and shape of objects will not change depending on how the object is viewed which is very different from traditional radiographs which are perspective projections. Objects that are closer to the screen or film appear smaller than objects that are farther away (Halazonetis 2005).

The use of images in orthodontics often involves cephalometric evaluation to determine the inter-relationships of the jaws and the teeth. Halazonetis (2005) states that traditional two-dimensional cephalometrics can be applied to three-dimensional images and the points that are used for cephalometric evaluations on traditional radiographs can easily be found on three-dimensional volumes or the radiographic reconstructions. When bilateral structures are to be evaluated, the computer can quickly and easily determine the exact midpoint between the two structures allowing many orthodontists to easily integrate CBCT technology

into their practice. Halazonetis calls for the orthodontic community to research clinical applications of CBCT and to consider the future direction of cephalometrics.

The use of the CBCT technology has recently expanded to include evaluation of treatment changes. A method utilized at the University of North Carolina for evaluating surgical changes has utilized CBCT technology for superimpositions in three dimensions. This method involves superimposition of pretreatment and posttreatment CBCT images on the cranial base structures using a software program with changes in the positions of teeth or jaws indicated by a change in color. Direct measurements of the changes can also be made in the software. This method of superimposition and measurement was shown to be valid and reproducible with minimal differences reported between three different operators. The difference between pretreatment and posttreatment measurements was no more than 0.26 mm. The limitations in describing this method are that there were only three operators and the same software programs were used for all the images, thus limiting the chance of errors in manipulation of the images. Despite this, the authors

concluded that superimposition technique was valid, reproducible, and that using CBCT was an ideal method for evaluating surgical changes since it even allowed identification of small changes (Cevidanes et al. 2005).

With increasing utility of CBCT imaging, many new systems have come to the market including the Imaging Sciences i-CAT™, Hitachi CB MercuRay™, NewTom 9000™, and the IMTEC Iluma™. Each system has different hardware and software to create and handle the images generated. To further complicate matters, third party software vendors have created programs specifically to view, analyze, and manipulate the images. To maintain interoperability and consistency among these different systems, the DICOM (Digital Imaging and Communication in Medicine) format has become a standard way for image files to be transferred between different devices. There is a detailed specification for the files to allow integrity of the patient data and accessibility in different settings. Although it does not guarantee interoperability, the goal of the standardized DICOM format is to allow information to be exchanged among practitioners, third party insurance companies, and to

allow images to be viewed on future equipment (Farman and Lapp 2003).

There are many differences between the various manufacturers CBCT machines including size, scanning position, type of detector, field of view size, how the images are reconstructed, resolution, and cost. Among these differences, the detector type requires a more technical investigation. Any CBCT machine will have an x-ray head and detector, but the detector is variable between machines with either an image intensifier or a flat-panel detector. The image intensifier converts the incoming x-rays to an optical signal and then to electrons by an input phosphor screen followed by a photocathode screen. The electrons are then accelerated through a field in the image intensifier and are detected by the output phosphor screen. The output phosphor screen reconverts the electrons to an optical signal which is further detected by a charge couple device (CCD) that is similar to those found in digital cameras. This final signal is then reconstructed by computers to assemble the final images. This process differs from a flat-panel detector in which the x-ray beam is converted to an optical signal by a cesium iodide scintillator

where the information is then detected by an amorphous silicon sensor. It is this information which is reconstructed to generate the final images (Baba et al. 2002). Examples of commercially available machines with an image intensifier detector are the NewTom 9000™ and CB MercuRay™ while examples of flat-panel detector machines are the i-CAT™ and Iluma™.

Different detector types lead to data sets that are different before being reconstructed by computers. Image intensifier detectors produce images having more noise than those produced with flat-panel detectors. There is also additional preprocessing by computer for the image intensifier detectors to reduce geometric distortions inherent in the detector configuration (Scarfe et al. 2006). This is mainly due to the fact that the image intensifier detector has a spherical input phosphor screen and photocathode screen while the output phosphor screen is flat. The distortion seen with this configuration is called pincushion distortion and the elimination of this distortion is the reason for the additional preprocessing of the images (Rudin et al. 1991). Baba et al. (2002) report that a flat-panel detector configuration does not have this image

distortion, veiling glare, and has a smaller imaging pixel than an image intensifier detector. In addition, the flat panel detector is considered to be more "geometrically robust" under rotation which is helpful in reducing or even eliminating image distortion concerns (Jaffray and Siewerdsen 2000). Smaller imaging pixels lead to a high pixel density on the flat panel detector which can help to increase spatial resolution. A downside of a high pixel density is that when a larger field of view is selected, large data volumes are created since more pixels can be detected; leading to information management concerns (Ross et al. 2006).

Geometric distortions are found in most two-dimensional dental imaging systems because the object being imaged is at some distance from either the film or the detector. The incoming energy source of either x-rays or light hits the object projecting on the film or detector leading to a projection error. Cone beam computed tomography reduces geometric distortion by generating and detecting x-rays that are almost parallel to each other. In addition, with cone beam computed tomography, the object is very near the sensor and any projection errors that do result are reduced by computer

reconstruction algorithms leading theoretically to exact measurements (Mah and Hatcher 2004).

Preliminary investigations conducted at the Case School of Dental Medicine have indicated subtle differences in the linear measurements of images obtained by CBCT lead to image distortion. A phantom was constructed utilizing 0.8 mm metallic markers placed 6.5 mm apart in the outer walls of a triangular shaped acrylic box. The phantom was scanned in the Hitachi CB MercuRay™ with settings for mA and field of view changed for each image. The measurements between the markers were recorded directly with a digital caliper and in the Accurex software and were repeated three times for reliability data. The results indicated that the measurements from the CBCT images were smaller than the direct measurements. In addition, the measurements were found to be more accurate in the center of the images with approximately 0.2 mm distortion near the periphery (Christopher et al. 2007). Although this distortion was evident, it was not statistically significant, and would hardly be considered clinically significant since it would represent approximately one voxel and may be below the spatial resolution of the machine at that setting.

Measurement error is also a possible explanation for the distortion that was seen since the 0.8 mm markers had to be measured directly with calipers. Perhaps there was better access to those markers at the center of the phantom versus the periphery. In addition, the CBCT scanner used was an image intensifier system which has been shown to have distortion in the periphery of the field of view (van der Zwet et al. 1995; Rudin et al. 1991; Fahrig et al. 1997).

Image distortion in an image intensifier system was clearly described by Rudin et al. (1991) where explanations for the distortions seen in image intensifier systems were related to the design of these detectors. The magnetic field of the earth can influence the path of electrons as they travel through the image intensifier. The size of the input phosphor screen is usually larger than the output phosphor screen, so any movement of the electrons as they move through the intensifier from the input to output screens can cause significant distortions. In addition, pincushion distortions are caused by spherical input phosphor screen and photocathode screen while the output phosphor screen is flat. These two effects can lead to images that are

distorted in the periphery (Rudin et al. 1991). This periphery distortion was illustrated by van der Zwet et al. (1995) who discovered that, when a grid was fixed to an image intensifier system, significant distortion was found in the periphery of the field of view. The problems with these images have prompted many researchers to look for ways to correct distortion. One approach used by Fahrig et al. (1997) was to scan a grid of steel beads and to mathematically correct the output images to match the known grid. They found that this method worked to eliminate distortion in the image intensifier detector system used in the tests (Fahrig et al. 1997).

The accuracy of utilizing three-dimensional imaging for craniofacial measurements has been well established using spiral CT scanners, commonly found in medical applications (Cavalcanti et al. 2004). Spiral CT differs from CBCT in that the x-ray projection is fan-shaped instead of cone-shaped. This fan-shaped beam requires multiple parallel helical revolutions around a patient to develop a three-dimensional volumetric reconstruction (Winter et al. 2005). To evaluate craniofacial measurements taken with a spiral CT scanner, Cavalcanti et al. (2004) utilized thirteen cadaver heads. The heads

were scanned at a high resolution setting with 3 mm between adjacent helical slices, 100 mA, and 120 kVp. A third party software package, Vitrea, was used to evaluate the images and measure craniofacial landmarks where five hundred and twenty measurements were made using both bone and soft tissue landmarks. In addition, each measurement was determined by two independent examiners at two different time points. These measurements were compared to soft tissue measurements taken on the cadaver heads using the 3 Space™ electromagnetic digitizer. The soft tissue was removed from the heads and the digitization process was repeated to collect the bony landmarks. Comparing the measurements from the CT images and the physical measurements of the cadaver heads, the spiral CT measurements were found to be both accurate and precise with no statistically significant differences between any of the measurements collected by each method (Cavalcanti et al. 2004). This study is very helpful in establishing the accuracy and precision of CT based measurements and lack of image distortion. However, it is difficult to fully apply this study to CBCT machines due to the vast

differences in design and technology between spiral CT and CBCT.

Spiral CT and CBCT were compared in a study conducted in Germany by Holberg et al. (2005). Four hundred seventeen teeth and the surrounding structures were divided into two groups; those that were imaged with spiral CT and those imaged with CBCT. The images were assessed by three clinicians who ranked image quality of the periodontal ligament space, the existence of metal artifacts or movement artifacts, and the image quality of the dentinoenamel junction. The examiners found that the CBCT images had poorer quality of both the periodontal ligament space and the dentinoenamel junction. Although there was an increase in the movement artifact with the CBCT images (due to a seventy-eight second image acquisition time), there was less metal artifact than with spiral CT images. The authors conclude that if fine dental structures or the periodontal ligament space is to be imaged then spiral CT is recommended. However, if major dental structures are to be examined, then CBCT is to be used since it provides acceptable image quality and lower radiation exposure compared to spiral CT (Holberg et al. 2005). The major limitation to this study was the

longer image capture time of the CBCT scanner of seventy-eight seconds. This was an incredibly long time for a patient to sit perfectly still and explains the increased movement artifacts seen in the CBCT images. This movement artifact may explain why the fine dental structures were more difficult to visualize clearly. Perhaps had a more modern scanner with a shorterr acquisition time been used, the periodontal ligament space and the dentinoenamel junction would have been visualized with a higher image quality.

Cone beam CT and spiral CT measurements were compared in an article by Kobayashi et al. (2004) where the author utilized five cadaver edentulous mandibles for investigation. The mandibles had holes of 2 mm in diameter drilled through both cortical plates at seven regions on each mandible which were then imaged in both the spiral CT and the CBCT. The spiral CT system was a RADIX-Prima™ system and the CBCT was a Dental 3D-CT™, with an image intensifier detector. After the scans, the mandibles were then physically sectioned where the holes had been drilled, and a digital caliper was used to measure from the top of the cortical reference holes to the alveolar ridge. For the computer images, the same

software package was used to measure the distances from the top of the cortical reference holes to the alveolar ridge for both the spiral CT and CBCT. A measurement error was calculated using the digital caliper measurements as the gold standard. It was found that CBCT measurements had a statistically significant lower measurement error than the spiral CT measurements. Measurements for seven regions of five mandibles were collected by evaluating both the buccal and lingual distance from the top of the cortical reference holes to the alveolar ridge. Therefore, each region had ten total measurements that were used to calculate the mean and standard deviation and this mean was utilized in a paired t-test comparison between the two CT methods. When the measurements for each of the seven reference holes were compared, three areas had statistically significant differences. Kobayashi et al. concluded that CBCT was more accurate for linear measurements than spiral CT (Kobayashi et al. 2004). There were some limitations in this study that warrant review since no reliability study was conducted. As a result the measurement method may not be considered reliable and the authors may have found different results if the project was repeated. The use

of the mean of only ten total measurements for comparing the seven regions is also a short coming. This mean was then utilized in a paired t-test. This is not the ideal situation for a statistical test since only ten measures exist. A larger sample size to include at least thirty measurements would have increased the power of this statistical test and would have helped make the results more convincing.

Lack of image distortion in CBCT machines was described by Yamamoto et al. (2003) in an article describing the development of the Hitachi CB MercuRay™, a system with an image intensifier detector. In order to assess image distortion, an acrylic pipe was placed parallel to the long axis of the scanner with an outer diameter of 9 mm and an inner diameter of 7 mm. The axial slice of the pipe was measured in the software for the area of the circular shape, the circumference length, and the circularity. The software measured values were compared to the acrylic pipe directly. There were differences in the calculated area of the circular shape and the circumference length with the software measurements by approximately 0.5 mm. No mention was made of the number of measurements taken, the machine

settings, or if any calibration of the machine was conducted prior to measuring. It was concluded that the system has enough performance to provide accurate three dimensional images for diagnosis (Yamamoto et al. 2003).

Araki et al. (2004) also utilized a Hitachi CB MercuRay™ to analyze the physical properties of generated images. In a method very similar to that described by Yamamoto et al. (2003), Araki et al. utilized an acrylic pipe phantom with sixty-one acrylic pipes of a known diameter. The phantom was scanned at 120 kV and 15 mA to generate DICOM files which were analyzed in a computer program to measure circularity which was defined as being equal to 1 for a perfect circle and less than 1 for any other shape. Since the acrylic pipes were fabricated to be perfectly circular, images generated from the CBCT should also be perfectly circular. The results showed that the CBCT images had 99% circularity which the authors interpreted to mean no distortion was present in the images, but no mention was made of where in the length of the pipe phantom the images were taken. In addition, no effort was made to compare the dimensions of the CBCT pipe phantom images to the actual dimensions of the phantom (Araki et al. 2004).

A similar study to evaluate geometric accuracy was conducted by Mozzo et al. using the NewTom 9000™ CBCT machine, another system with an image intensifier detector. A geometric phantom was constructed with two circular inserts of known width and height and was scanned in the horizontal position and tilted thirty degrees. The heights and widths of the circular inserts were measured on the software. In order to minimize measurement errors, the examiners utilized a density calculation feature of the software that automatically set the edges to be measured based on density differences of the inserts to the acrylic around them. The measurements were repeated three times at different areas around the circular inserts and the average was calculated. Comparing these average measurements to the known height and width of the circular inserts, it was determined that there was approximately a 1% difference in width measurements and a 2% difference in height measurements depending on whether the object was horizontal or tilted thirty degrees. The software had a tendency to underestimate the actual values of the inserts. The conclusions drawn from this study were that the system demonstrated good accuracy despite the spatial

orientation of the object. (Mozzo et al. 1998). This study did not mention the machine settings or the location along the phantom where the measurements were taken. It may be that if a slice was taken near the periphery of the phantom there might be an increase in geometric distortion. However, since only one slice was measured, it is not known for sure if the accuracy noted in the study applies throughout the image.

Another study of the NewTom 9000™ CBCT was conducted in Germany by Marmulla et al. (2005) where the goal was to evaluate the geometric accuracy of the scanner using a polymethylmethacrylate cube that was 12 cm on each edge with an accuracy of 0.01 mm. Thirty-six cylinders, 5 mm in diameter, were bored into each side of the cube for a total of 108 cylinders and 216 cylinder intersections. These cylinders were left open and had an exact distance of 20 mm between any two in each plane of space. The cube was scanned in the NewTom 9000™ with a slice pixel size of 0.29 mm and the differences of the CBCT cylinder intersection distances were compared to the exact known cylinder intersection differences. There was a mean difference between the two distances of 0.13 mm which was not considered to be significant since a minimum relevant

distance of 0.5 mm was determined, below which differences may be related to resolution of the image. In addition, the authors found that the images were in no way distorted and the differences between the image measurements and the exact known measurements were spread evenly throughout the object. The authors concluded that the NewTom 9000™ CBCT was capable of producing images where the distortion is below the resolution of the images (Marmulla et al. 2005). Limitations of this study include a lack of reliability testing and no mention of the CBCT settings used for the scans. In addition, it was mentioned that "the object was somewhat bigger than the scanned volume" and that only 176 of 216 cylinder intersections were represented (Marmulla et al. 2005). It would not have been difficult to accurately describe the size and characteristics of the volume that was captured and this information may have been very useful to practitioners when planning or taking CBCT images with the NewTom 9000™.

Lascala et al. (2004) evaluated the measurements taken with a NewTom 9000™ CBCT on human skulls with eight dry human skulls having nineteen 2 mm diameter metal markers placed in various locations on both the facial

skeleton and the cranial base. The distance between the markers was measured with a digital caliper. Then the skulls were placed in a water bath and imaged in the NewTom 9000™ CBCT at a fixed setting of 7 mA, 85 kV, and 70 seconds. The proprietary software supplied with the NewTom scanner was used to measure the same markers in the CBCT images for comparison to the digital caliper measurements. The axial sections were used for the first collection of software measurements and the sagittal or coronal sections were used for a second collection with 2 mm between all sections. It was found that measurements from the CBCT were less than those taken with a digital caliper and there was statistical significance for the measurements taken at the cranial base. The conclusion was that, although there were statistically significant differences in the cranial base measurements, the NewTom 9000™ scanner was not designed to evaluate these areas. In its capacity as a dentomaxillofacial imaging system, outside the cranial base, the NewTom 9000™ CBCT can be used for linear measurements (Lascala et al. 2004). There were some underlying weaknesses to this study that need to be taken into account. First, the 2 mm diameter metal markers allow for measurement error with the

digital calipers, but no mention is made as to whether the markers were measured at the ends or the middle of the marker. If the marker was measured at the ends, this could inflate all direct measurements by up to 2 mm, or 1mm at each marker, versus measuring in the center of the marker. There was also no mention of where measurements were taken at the markers in the software. Beyond this, there was no reliability study that was conducted to evaluate the ability of the examiners to reproducibly measure these same points. Perhaps the examiners routinely "over-measured" the direct caliper measurements; a systematic measurement error. Finally, an evaluation of the differences between the various axial sections was not conducted. It would have been a simple statistical calculation to determine if there was a statistically significant difference of the measurements taken between the axial and sagittal or coronal sections.

The accuracy of linear measurements has also been evaluated on the i-CAT™, a flat panel detector CBCT. Hilgers utilized twenty-five human dry skulls to make measurements on the temporomandibular joint. Eleven anatomical landmarks were predefined and then marked on

the skulls which were then imaged with the i-CAT™ set at a 20 second scan, 1-3 mA, and 120 kVp. In addition, the skulls were studied utilizing conventional lateral cephalograms, posterior-anterior cephalograms, and a submentovertex projection. From the eleven anatomical landmarks, ten linear measurements were made with the measurements first collected on the dry skulls using a digital caliper at three independent times. This was considered to be the anatomic truth to which the i-CAT™ images and the different radiographs would be compared. The same linear measurements were conducted three independent times on all the collected images and the distribution of independent repeats was considered normal, so the mean for all the measurements for a specific image was used for analysis. Analysis of variance (ANOVA) was used to test for differences among the mean measurements dimensions, followed by a Dunnet t-test to compare the different imaging methods to the anatomic truth. The natural log of the standard deviations was used to report intraexaminer reliability. The results indicated no statistically significant difference between the anatomic truth and the i-CAT™ measurements, but there were differences for the

different radiographic projections that were attributed to projection and magnification errors. In addition, the CBCT measurements were highly reliable with standard deviations lower than even the experimental errors in the digital caliper measurements while the radiographic standard deviations were significantly greater. Hilgers et al. concluded that CBCT images allowed for measurements that were accurate with a near exact reconstruction of the temporomandibular joint in all dimensions (Hilgers et al. 2005). This study was well designed and had fifty measurements that were repeated multiple times with a limitation that the measurements were all localized to the temporomandibular joint region. If there was any distortion in any other portions of the image, it would not have been detected by this study.

The accuracy of three-dimensional measurements using an i-CAT™ was examined by Pinsky et al. (2006) using sixty-five simulated intraossesous defects in an acrylic block and twenty-one simulated defects in a dry human mandible. Holes were drilled to a predetermined width and depth to simulate the defects. After the holes were drilled, the objects were scanned in an i-CAT™ at 98 mAs, 120 kVp, and a voxel size of 0.2 mm. The eighty-five

simulated defects were evaluated by five examiners using the proprietary i-CAT™ software. The examiners were trained but not calibrated and the measurements were repeated twice with at least one week in between to obtain reliability data. Interclass and intraclass correlation coefficients showed excellent intraexaminer reliability and interexaminer reliability ($R > 0.90$). The mean measures were compared to the known predetermined hole width and depth with t-tests. The measured height in both the acrylic block and the dry mandible were statistically significantly less than the predetermined values. However, underestimation of actual depth determined by the CBCT images was merely the same size of the voxels (0.2 mm) used in the images. The authors concluded that, although the underestimation of simulated defect height was statistically significant, it was not clinically significant and that clinically accurate images can be expected from i-CAT™ CBCT imaging (Pinsky et al. 2006). The study was conducted on dry human mandibles which can lead to ideal imaging conditions. By comparison, images of live patients may not exhibit the same clarity as a dry human mandible or acrylic block, and therefore, measurement errors may be

greater. This point was noted by the authors who called for further clinical studies to validate the results (Pinsky et al. 2006).

Predrag Sukovic (2003) described the resolution performance and utility of the DentoCAT™ scanner with a flat panel detector from Xoran Technologies. The cone beam scanner described was reported to have "high and isotropic spatial resolution, undistorted images, compact size, and relatively low cost." In order to test this, a visual assessment of a spatial resolution bar phantom was conducted along with a calculation of the modulation transfer function (MTF). This is a way to describe the resolution in terms of how much of the spatial frequency is transferred to the final image. Compact size and relatively low cost are difficult to dispute, but the statement about isotropic spatial resolution is questionable. By definition, isotropic means the same throughout. However, Sukovic claimed that the measured values of spatial resolution "for the off-central slice were only slightly degraded" (Sukovic 2003). No mention was made as to the amount of degradation and there were no data to support the claim of undistorted images.

The flat panel detector has been reported by Baba et al. (2002) to produce a higher spatial resolution than the image intensifier detector, but the flat panel detector described was not a commercially available system and it was designed to make comparisons with a constructed image intensifier. The spatial resolution was determined by using a high contrast bar pattern phantom with the flat panel detector able to resolve a 0.35 mm pattern in all planes of space at the smallest voxel size setting of 0.169 mm. The image intensifier resolved 0.35 mm in the horizontal plane, but 0.40 mm in the vertical plane at the smallest voxel size setting of 0.205 mm. According to Baba et al., this higher spatial resolution of the flat panel detector provides increased utility compared to image intensifier detector systems. A limitation of this study is that the machines evaluated are not commercially available. In addition, there were not equal voxel sizes used for the comparison of the two different detectors. Lastly, Baba et al. state that spatial resolution differences of a hand phantom, when rendered as a volumetric image, are "obviously more accurate than those taken by the image intensifier

system." Such a statement is subjective since the images were not evaluated by a third party.

In a separate article in 2004, Baba et al. also compared a prototype flat panel detector to an image intensifier detector for spatial resolution and image quality of a skull phantom. The spatial resolution was evaluated with a high contrast bar phantom. Images of the phantom were collected utilizing similar voxel sizes and exhibited equivalent spatial resolutions. In addition, the field of view of the flat panel detector was equivalent to the field of view of the image intensifier system. The skull phantom was also imaged by the flat panel system and the image intensifier system. They reported that images produced by the flat panel system were clearer than those of the image intensifier detector. Higher resolution was noted and the surface appeared smoother on the images taken with the flat panel detector (Baba et al. 2004). This subjective evaluation was not supported by any data and the images were not evaluated by a third party.

There are data that do clearly support a similar claim of Ning et al. A line pair phantom was imaged and modulation transfer function (MTF) was calculated for a

flat panel detector system and an image intensifier system. The results clearly show that the flat panel system displayed better spatial resolution than the image intensifier system (Ning et al. 2000).

The high spatial resolution associated with cone beam CT technology was deemed very useful for the evaluation of the temporal bone, an anatomic area of mainly bony structures. In a study conducted by Gupta et al. (2004), spiral CT was compared to cone beam CT for the assessment of structures of the temporal bone, specifically the anatomic structures of the middle and inner ear. The author utilized an existing spiral CT system and an experimental flat panel imager CBCT system to collect images of four dry human temporal bones. One temporal bone was left unaltered, one had laser induced lesions, one was fitted with a cochlear implant, and the final bone was fitted with a middle ear hearing aid. The goal was to determine which of the different imaging systems could clearly distinguish the lesions and handle the artifacts. The images were collected and scored by three independent examiners. The examiners were told to evaluate how clearly defined structures were in the different images and the result was a significantly

higher score for the cone beam CT than the spiral CT images. The authors concluded that this was due to the higher spatial resolution of the flat panel imager cone beam CT system, which was especially obvious in high contrast areas like the middle and inner ear. The authors went on to state that the cone beam CT images had slightly lower contrast resolution, but that, in the images of this part of the body, this was not a drawback unless an operator was searching for soft tissue problems (Gupta et al. 2004). The main difficulty of this study is in the applicability of these results to dental maxillofacial imaging. Although the anatomical region examined consisted mainly of bony structures similar to the jaws, there were many differences and the argument could be made that this study does not apply to the maxillofacial regions. In addition, no mention was made about blinding of the participants. Perhaps it was very clear as to which machine made each image and the participants routinely picked one machine over the other. There were also no basic data to support the claims of higher spatial resolution other than theoretical calculations based on the physics of the detectors used and the visual assessment of the images by the examiners.

Spatial resolution was a parameter evaluated by Palomo et al. (2006) in a study to evaluate the effect of different mA settings and copper filters on image resolution of a Hitachi CB MercuRay™ using a C-phantom, a high contrast bar pattern phantom with nine sets of four metal bars in water with the metal bars placed at decreasing distances from each other in a parallel manner. The phantom ranges from 0.35 mm to 1 mm of resolution detection and, in order to evaluate the images of the phantom, an operator selects the last set of lines with clear separation between them. Palomo et al. took images of the C-phantom with differing mA settings, with or without a copper filter. Ten professionals were trained to evaluate the phantom images and a q-sort was used to rate the images based a lowest resolution to highest resolution scale. To further analyze the spatial resolution, two operators assigned a resolution value to the images based on the phantom manufacturer guidelines. Both methods agreed that higher mA settings and a copper filter showed the best resolution (Palomo et al. 2006). This study clearly illustrated two ways to interpret the images of a high contrast spatial resolution phantom and

that both have a high level of agreement for spatial resolution interpretation.

The impact of the number of projections on the quality of CBCT images was researched by van Daatselaar et al. (2004). A phantom consisting of three cylindrical shapes of different materials was imaged with a bench top mounted x-ray system. In addition, a head phantom was imaged. Projections were taken from different angles every two degrees to give one hundred and eighty total projections. The images were obtained from the projections and then other images were made after the deletion of projections continuing this process until there were only a few projections taken. The resulting images were computer evaluated for the noise, contrast, and resolution of each set of projections. It was determined that the minimum number of projections needed to obtain clinically useful images was thirty-three. Interestingly, the contrast and noise were greatly influenced by the number of projections, but the resolution was not affected unless there were very few projections. The resolution also differed depending upon the material used (van Daatselaar et al. 2004). This study is interesting in that it begins to evaluate the

importance of the number of projections on resulting images. Its application to CBCT imaging is that many systems allow a specification for the amount of time a scan is to take place with an increased amount of scanning time allowing for additional projections or frames to be taken. One example of this is found with the i-CAT™ CBCT system. A ten second scan has one hundred and sixty frames, a twenty second scan has three hundred and six frames, and a forty second scan has five hundred and ninety-nine frames (i-CAT™ Operators Manual 2005).

Recent publications state that the technology is "initiating a trend in which traditional orthodontic imaging is being replaced by 3-D imaging" (Mah et al. 2006). The advantages of this technology are the following: fairly low cost and convenient size compared to traditional CT machines, three-dimensional images of the dentofacial regions, ease of operation, relatively quick scans, low radiation exposure, and the elimination of multiple x-rays to localize anatomic structures (Hatcher 2006). All necessary radiographs can be collected in one scan in less than one minute. In addition, views not previously available can be created

such as axial slices, sagittal slices, and separate views of the right and left sides of the head (Kau et al. 2005). It has been stated that "this new technology has become the standard of care in diagnosing and treating dental pathology, abnormalities/problems in craniofacial growth and development, and in performing analysis for mixed dentitions, as well as for dental implants" (Winter et al. 2005). Despite the reported advantages of CBCT technology, a limited amount of research has validated individual machine images for accuracy in both linear and angular measurements by comparing them to measurements taken directly on either dried skulls or phantoms. A review of the literature finds inadequate research documentation of basic information such as image size, measurement accuracy, distortion, and spatial resolution for the various CBCT machines. In addition, there is limited mention of machine settings and their effects on the images. Advances in CBCT technology have occurred in the past few years, with many new and different CBCT machines coming to market. Information on the images produced from these systems becomes more crucial as clinicians begin to use the images for diagnosis and treatment planning. As Rudin et al. stated in their

article on image intensifier distortion, "it is important to quantify image distortion whenever careful spatial measurements are to be obtained from the images" (Rudin et al. 1991). Clearly, as CBCT technology becomes adopted by clinicians, a full understanding of all parameters of the images generated by the different manufacturer's machines and the effect of different machine settings is crucial to make optimal use of this technology.

STATEMENT OF HYPOTHESIS

The purpose of this study is to determine the measurement accuracy and spatial resolution of a commercially available CBCT dental imaging system. It is hypothesized that there is no difference between direct physical measurements of a phantom compared to CBCT measurements of the same phantom. If rejected there is a difference between measurements taken directly from a phantom compared to CBCT measurements of the same phantom.

Image Distortion and Spatial Resolution of a Commercially Available CBCT

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American Journal of Orthodontics & Dentofacial Orthopedics
Manuscript Draft

Title: Image Distortion and Spatial Resolution of a Commercially Available CBCT

Article Type: Original article

Keywords: Cone beam computed tomography, CBCT, flat panel detector, i-CAT, image accuracy, image distortion, image resolution, image settings, phantom

Objectives: To evaluate images produced by a commercially available CBCT for measurement distortion and spatial resolution for all settings and in all dimensions. **Methods**: Phantoms were specially constructed for scanning in the CBCT machine. A CIC-Phantom for analyzing distortion contained 0.3 mm diameter chromium metal markers approximately 5 mm apart in three planes of space. This phantom was scanned in the CBCT machine using all twelve of the possible settings at a commercial dental imaging center. The distance between the markers was measured three times using a DICOM viewer and was also measured three times directly with fine tipped digital calipers. A line pair phantom called the C-Phantom was also utilized to evaluate image resolution. Thirty evaluators analyzed images and assigned a resolution according to the separation of the line pairs. **Results**: There were no statistically significant differences between any of the image settings, in any of the three dimensions, or in images divided by thirds in terms of absolute differences between the CBCT measurements and the direct digital caliper measurements. A side by side comparison of the CBCT measurements to the direct digital caliper measurements showed a statistically significant difference ($p < 0.01$), but not a clinically significant difference in most situations (< 0.1 mm). The image resolution variation was determined to be largely explained by smaller voxel size followed by increased scan time. **Conclusions**: A CBCT can be considered to have clinically accurate measurements in all parts of the image and with all image settings. Smaller voxel sizes and longer scan times will lead to higher resolution images.

Introduction:

Cone-beam computerized tomography (CBCT) is a burgeoning technology with the ability to change the way that orthodontists look at their cases. CBCT has the ability to represent three-dimensional structures in three-dimensions. In years past, this has only been possible with study models and it was not possible for the hard tissue structures of the craniofacial area to be imaged. In dental imaging, cone beam computerized tomography (CBCT) is making inroads into many dental offices and dental imaging centers as a way of representing three dimensional structures. Recent publications state that the technology is "initiating a trend in which traditional orthodontic imaging is being replaced by 3D imaging"[1]. The advantages of this technology are the following: fairly low cost and convenient size compared to traditional CT machines, three-dimensional images of the dentofacial regions, ease of operation, relatively quick scans, low radiation exposure, and the elimination of multiple x-rays to localize anatomic structures[2]. CBCT technology has been reported to have approximately equivalent radiation as a full mouth series with D-speed film or equivalent to three to seven panoramic radiographs[3,4,5]. Despite this slight increase in radiation, all necessary radiographs can be collected in one scan in less than one minute. In addition, views not previously available can be created such as axial slices, sagittal slices, and separate views of the right and left sides of the head[6]. The uses of these types of images include dental implant planning, temporomandibular joint imaging, locating the mandibular nerve canal, studying mixed dentitions, planning orthodontic temporary anchorage devices, identifying and locating

pathological lesions, evaluating endodontic problems, locating supernumerary teeth, evaluating alveolar ridge height and volume, evaluating growth and development of the craniofacial complex, analyzing airway, and studying the development of surgical guides and stents[7]. Published literature has gone so far as to suggest that "this new technology has become the standard of care in diagnosing and treating dental pathology, abnormalities/problems in craniofacial growth and development, and in performing analysis for mixed dentitions, as well as for dental implants"[8].

Dental radiographs and photographs are images commonly used in the diagnosis and treatment planning of patients in orthodontics. These two dimensional images are subject to geometric, rotational, and head positioning errors that can lead to the area of interest being misrepresented[9]. Many clinicians have searched for ways to have three dimensional (3D) representations of anatomical structures to avoid these problems. Literature on the subject has stated that the development of three dimensional modeling of patient anatomy would help to decide appropriate treatment options, monitor changes, detect treatment results, and measure outcomes more accurately[9].

The measurement accuracy of CBCT images has been studied in the past on different machines with varied results. Some authors described no statistically significant differences between CBCT images and the anatomic truth[10], while others illustrated differences that were not considered to be clinically significant[11,12,13,14,15].

There are two main types of CBCT detector designs – image intensifier detectors and flat panel detectors. It has been reported that there is additional noise,

distortion in the periphery of images, and intensive computer processing involved in image intensifier images due to the geometric designs of these detectors[16,17,18,19]. Flat panel detectors do not have these limitations inherent in the design of the detectors; therefore the machines with these detectors have been reported to be free of distortions with smaller possible imaging pixels[20]. In addition, it has been reported that flat panel detectors have a better spatial resolution than image intensifier systems[20,21,22].

The purpose of this study is to determine the measurement accuracy and spatial resolution of a commercially available CBCT dental imaging system.

Materials and Methods:

The study utilized two specially designed phantoms to determine image size, measurement accuracy, and spatial resolution of a CBCT machine. The phantoms were scanned using a flat panel detector CBCT machine (i-CAT model number 9140-0035-000C - Imaging Sciences International Inc. – Hatfield, PA) at a commercial dental imaging center (Toothpics Dental Imaging Center in Beachwood, Ohio).

The first phantom, fabricated at the Craniofacial Imaging Center of the Case Western Reserve School of Dental Medicine (CIC-phantom), was custom made for this project (Figure 1). The CIC phantom was made of acrylic with embedded chromium spheres (Small Parts Inc – Miami Lakes, FL) following the x, y, and z Cartesian planes. The spheres were of 0.3 mm diameter and were placed at approximately every 5 mm from a common central point of intersection of x, y, and z planes. A phantom with measurement markers at regular intervals in all three

dimensions was fabricated and called the CIC-phantom. The CIC-phantom was specifically designed to measure the image size and analyze measurement accuracy.

The second phantom, named the C-phantom (Figure 2), was a pre-existing high contrast line pair phantom (The Phantom Laboratory – Salem, NY) made of acrylic filled with water containing embedded metal plates. Nine series of four plates were placed at decreasing distances apart corresponding to spatial resolutions from 1 mm to 0.35 mm. The C-phantom was designed to test image resolution by determining at which series of plates a clear distinction exists between each individual plate.

The data were collected using all twelve of the available settings for the CBCT machine at the dental imaging center. The phantoms were placed in the machine in such a way so that the center of the phantom was in the center of the scout images, which represented the field of view of the particular scan setting. The raw data were collected from the machine and reconstruction software provided by the CBCT manufacturer (i-CAT software version 2.2.21) was used to create a reconstructed file from the raw data. Once the reconstruction was completed, the information was exported and saved as a DICOM file. The data were then imported, analyzed, and measured utilizing Accurex software version 1.1 (Cybermed Inc. - Seoul, South Korea).

The image size was measured using the embedded markers. The periphery of the available image was determined and measured in all dimensions in the software to give the image size. To evaluate for measurement accuracy, the center to center of

the markings were measured directly on the CIC-phantom with fine point digital calipers (Mitutoyo 500 Series – Mitutoyo America Corporation – Aurora, IL), accurate up to 0.01 mm resolution. Manual measurements were collected and compared to the markings as measured digitally measurements in the software. The digital images were evaluated using the sagittal slices for height and the axial slices for width and depth. It was considered to be the appropriate slice when all of the markings were evident in the same slice. All measurements, direct and on the computer, were taken at three separate times. The mean measurement was used to minimize measurement errors and a standard deviation was also calculated.

The image resolution was collected by determining the separation of the lines from the C-phantom in sagittal slice images. All of the images were standardized for brightness and contrast and were magnified to the same extent. Thirty volunteers from the student doctors and residents at the Case Western Reserve University School of Dental Medicine were used to evaluate the collected images. A PowerPoint presentation was used to present the images in a standardized format on a 21 inch LCD flat panel monitor (Dell Computer Corporation – Round Rock, TX) in a dim room. The evaluators were first asked to determine the choices which showed a clear, distinct separation of the four lines from the line pair phantom - which is the manufacturer's recommendation for interpretation. In addition, the evaluators were asked to determine the choices which allowed an identification of a pattern of four lines although the lines may not have had a clear delineation. Twenty-four slides were shown with two separate slides for each image setting. The average resolution

for each image setting was calculated by averaging both readings (R1 and R2) for each method of evaluation. A ranking of the images based on the average resolution was also conducted. The ranking of 1 represented the best spatial resolution and 12 represented the worst spatial resolution. This method of spatial resolution evaluation is similar to a method described by Palomo[23].

Data Analysis and Statistical Methods

The data collected were continuous data and were appropriately organized using Microsoft Excel 2007 spreadsheets (Microsoft Corporation – Redmond, WA). Microsoft Excel 2007 was used for descriptive statistics and SPSS 14 (SPSS Inc. – Chicago, IL) was used for further analysis. To assess measurement accuracy, the absolute mathematical differences were used to describe any differences between Accurex software measurements and direct digital caliper measurements. The same procedure was also conducted with the images further divided into thirds for each dimension. The mean absolute differences for the twelve image settings in all dimensions were determined to be normally distributed, therefore an analysis of variance (ANOVA) at $p = 0.05$ was used to determine if there were any significant differences between the settings or dimensions. Further analysis pooled all the measurements for all settings, dimensions, and thirds. After determining the data were normally distributed, measurements from the CBCT were then directly compared to the same measurements taken directly with digital calipers using a paired sample t-test at $p = 0.05$. Measurement differences of less than 0.1 mm were considered to be clinically insignificant by the authors.

To determine how the various image settings affected the observed resolution values, a multiple regression was used. The dependent variable was the image resolution value and the independent variables were image size, seconds of scan, and voxel size. The coefficient of determination (R^2) was calculated for each image parameter and for the combination of the two most influential parameters.

Reliability

For reliability of the measurements, the measures for the scans of the CIC-phantom were repeated multiple times. An intraclass correlation coefficient was used to assess measurements taken at different times to assess intra-operator reliability. In addition, the standard deviations were established for each of the measurements and the overall standard deviation for each image setting and dimension was determined. A calculation of +/- 2 standard deviations was calculated to show the range of where 95% of measurements would be expected to fall. For the reliability of the C-phantom images, each image was presented twice to assess intra-examiner reliability. Reliability was calculated using an intraclass correlation coefficient.

Results:

Measurement Accuracy

The analysis of variance for the mean absolute differences between the CBCT measurements and the direct digital caliper measurements did not indicate any statistically significant differences ($p = 0.964$) between any of the image settings or dimensions (Table 1). There was a general trend of the CBCT measurements to be smaller than the direct digital caliper measurements in 94.4% of the measurements

(Table 1). Further subdivision of the dimensions into thirds also did not show any statistically significant differences ($p = 0.259$) between any of the image settings or thirds of the images (Table 2). A paired sample t-test between the CBCT measurements and the direct digital caliper measurements indicated a statistically significant difference between the CBCT measurements and the direct digital caliper measurements at the $p < 0.01$ level (Table 3).

Image Resolution

The twelve image settings were evaluated by thirty evaluators with no exclusions. The average image resolution for the clear separation of the lines of the line pair phantom ranged from 0.622 mm to 0.860 mm with the 6 cm, 40 second, 0.2 mm voxel being the best ranked image and the 13 cm, 10 second, 0.4 mm voxel being the poorest ranked image. The average image resolution for the identification of a pattern of four lines of the line pair phantom ranged from 0.398 mm to 0.704 mm with the 6 cm, 40 second, 0.2 mm voxel being the best ranked image and the 13 cm, 10 second, 0.4 mm voxel being the poorest ranked image. The coefficient of determination (R^2) indicated that voxel size had the most effect on resolution. 52.1% of the variation of the clear separation resolutions and 57.8% of the variation of the pattern identification resolutions were explained by voxel size alone. Voxel size was followed by seconds with 43.9% of clear separation resolution variation and 39.4% of pattern identification resolution variation explained by scan time. Image size had the least effect on resolution with 22.3% of clear separation resolution variation and 23.2% of pattern identification resolution variation explained by differences in image

size. A combination of voxel size and seconds was able to explain 60.1% of the variation in clear separation resolution and 62.1% of the variation in pattern identification resolution (Table 4).

Reliability

Measurements taken from the CBCT and directly with digital calipers demonstrated excellent intra-operator reliability with intraclass correlations of 0.892 for CBCT measurements and 0.902 for direct digital caliper measurements. The reliability for measurement accuracy utilizing the standard deviations of the measurements for all twelve image settings measured by the CBCT and directly with digital calipers ranged from 0.017 mm to 0.072 mm. This indicated that 95% of all the measurements were taken within a range +/-0.144 mm maximum from each other (Table 5).

The thirty evaluators for the evaluation of the C-phantom demonstrated excellent reliability. This excellent reliability was demonstrated in both methods of evaluation, but was higher when the evaluators were asked to identify a pattern of four lines although the lines may not have had a clear delineation (intraclass correlation of 0.782 for a clear separation of lines and 0.914 for an identification of a pattern of lines) (Table 4).

Discussion:

The expanding use of CBCT technology is beneficial to both patients and practitioners. A thorough understanding of the theoretical limits of the machines is required to optimize their use. This study utilized phantoms to glean information

about measurement accuracy and image resolution. The CIC-phantom and the C-phantom had very different purposes, but a thorough evaluation of the data produced illustrates some of the technical capabilities of this particular CBCT machine. This information may be used by practitioners to determine which settings may be most ideal for a particular circumstance. A full explanation of the image settings for the CBCT machine used in this study (i-CAT model number 9140-0035-000C - Imaging Sciences International Inc. – Hatfield, PA) is found in Table 6.

The CIC-phantom was constructed out of acrylic with chromium metal markers embedded at approximately 5 mm increments. The metal markers were not always exactly 5 mm apart due to random errors during fabrication. The markers were 0.3 mm in diameter and this small size made it very difficult to precisely position them. Furthermore, when scanned in the CBCT, some metal artifact was noted. This "halo" effect made some of the metal markers appear almost two times larger than they actually were and some appeared more elongated than perfectly round. To minimize any effect on measurement that this might have, the center of the point of maximum density was measured. It is believed that this method minimized errors in the measurement of the images in the software.

To fully analyze the accuracy of measurements from the CBCT and from the direct digital caliper measurements, it was determined that each measurement between each marker would have to be taken three times. This served to minimize measurement errors and allowed the establishment of a mean and standard deviation. The mean of the three measurements for the CBCT was then compared to the mean of

the same three measurements for the direct digital caliper measurements. An absolute difference was calculated for these point to point measures and an average of all the absolute differences for the particular dimensions and image settings was calculated. This method may have overlooked areas of individual variation between points, so the data was further broken down into thirds for each dimension to see if any differences existed between the periphery and the center of the images. The analysis of variance that was conducted to test the hypothesis that there were no statistically significant differences between any of the image settings or dimensions and it clearly showed this to be the case ($p = 0.964$). When the analysis of variance was conducted to look for differences between the image settings or any of the thirds of the images, it also showed no statistically significant differences ($p = 0.259$) (Tables 1 and 2). Therefore, it can be stated that all the image settings, the different dimensions, and the periphery vs. center of the images are similar in what is measured with no image setting, dimension, or third more accurate than any other.

Once it had been established that no image setting, dimension, or third was more accurate than any other, a further analysis was decided upon to directly determine if the CBCT measurements were different from the exact same measurements taken directly. The measurements from all points, from all settings, and in all dimensions were then pooled since there were no statistically significant differences found by ANOVA. The CBCT measurements were then compared to the same direct measurements with a paired samples t-test. This test was selected because the only difference in the measurement of the markers was the form of

measurement used. The paired samples t-test illustrated a statistically significant difference between the CBCT measurements and direct digital caliper measurements ($p < 0.01$) (Table 3).

The CBCT had a tendency to underestimate the actual values of each individual measurement. This underestimation occurred in 94.4% of the measurements. This is a similar finding to a study conducted by Mozzo in which software measurements underestimated the actual size of circular objects[12]. Lascala also reported computer based linear measurements to be smaller than direct digital caliper measurements of dry skulls[14]. This is most likely due to a systematic error in the CBCT software. Although the differences are less than 0.1 mm and are not clinically significant, this may be an issue when multiple measurements are added together. An example of this would be arch perimeter analysis. For an individual tooth the small underestimation may be insignificant, but when added over an entire arch, there may be significant differences.

Although it was demonstrated that there are differences in the measurements taken in software compared to direct measurements, a question as to how this will affect a practitioner must be raised. In this situation it was determined that although there was statistical significance, this does not mean that the differences are clinically significant. It was determined that when taking larger measurements, as in orthodontics or implant planning, any differences less than 0.1 mm would not be clinically significant. However, if a situation called for small scale measurements

then perhaps the differences between the CBCT and direct measurements would have more significance.

A review of the absolute differences between the CBCT measurements and the direct digital caliper measurements (Tables 1 and 2) shows that no single value is greater than 0.1 mm. The differences that are seen are consistent among all settings, dimensions, and thirds, but the differences are not clinically relevant. These results are similar to the study conducted by Pinsky where it was determined that although the 0.2 mm differences between i-CAT software measurements and direct measurements may be statistically significant, the differences are not clinically significant[15]. Marmulla had similar results with 0.13 mm differences between NewTom 9000 software measurements and direct measurements, but determined that this was not clinically significant since it was less than the maximum resolution possible by the machine[13]. Although Hilgers did not find statistically significant differences when comparing i-CAT measurements to the anatomic truth on skulls, the mean absolute difference as calculated in the current study was 0.196 mm[10]. Although this is approximately double the largest mean absolute difference in the current study, the difference may be due to the fact that high contrast metal markers of 0.3 mm diameter were used in the current study, allowing more accurate measurements than those taken on dry skulls. The software based measurements from the CBCT are acceptable for routine clinical diagnosis and treatment planning with no concern of distortion related to the image setting, dimension, or third of the image.

The image spatial resolution was also evaluated in this study. This is an important image parameter since it determines when two separate objects can be distinguished from each other. The thirty evaluators were highly reliable in their ability to assign resolution values to the CBCT images in two different ways: 1) to determine the choices which showed a clear, distinct separation of the four lines from the line pair phantom; 2) to determine the choices which allowed an identification of a pattern of four lines although the lines may not have had a clear delineation. The aim of the first way of determination was to follow the C-phantom manufacturer's recommendations for evaluation. This is the technical limit of the machine. The aim of the second way of determination was to see up to what point human evaluators can still distinguish what is really there. The evaluators were only told that there were four vertical lines. A similar situation occurs daily in clinical practice when imaging a specific area – although an image may not be perfectly clear, it may still adequately represent the structures and be of diagnostic value. In the case of the C-phantom, the diagnostic value would be to determine if there is separation between the lines. Clearly, the images were able to answer this question to a higher level of resolution than when the manufacturer's recommendations were used. Interestingly, the rankings are the same for the best five images and for the worst two images (Table 4).

The image spatial resolution was very highly dependent upon voxel size. The coefficient of determination (R^2) shows that over 50% of the variation in image resolution is explained by the voxel size alone. This makes technical sense given that the voxel is the smallest unit that can be detected in an image. The smaller the voxel

size, the better the resolution should be. Theoretically, a spatial resolution equivalent to the smallest voxel size should be achieved. However, this does not hold true. A possible explanation includes metal artifact and the "halo" effect seen earlier with the metallic markers. Another explanation comes from the fact that there is noise in the images. Noise is the detection of energy from sources other than the x-ray tube such as light and scatter radiation. Technical discussions with the manufacturer revealed that the i-CAT CBCT deals with image noise by binding pixels from the detector in a 2x2 fashion. This allows the information to be pooled and increases the signal to noise ratio. Although this is done, it still does not totally eliminate the noise which may explain why the evaluators could not resolve equivalent to the voxel size. The scan time also influenced the resolution. Technically this makes sense since increased time leads to increased exposure and the increased exposure to more information being captured. More information, due to more frames being captured, is responsible for clearer images with less noise, which is why longer scan times illustrate higher spatial resolution.

Practitioners utilizing CBCT technology must keep in mind that measurement accuracy and spatial resolution are very different concepts. Measurement accuracy is how well the CBCT machine detects the actual distance between two objects that are separated by a distance. The spatial resolution is the ability of the CBCT to separate two objects of close proximity. The measurements from CBCT are accurate to less than 0.1 mm when there are larger distances between two objects, however, this is not always the case. As shown in the study, the minimum spatial resolution is 0.86 mm.

This means that the CBCT can detect a difference in two objects when they are a minimum of 0.86 mm apart. Measuring the distance between two objects closer than 0.86 mm apart would be futile since the machine would not be able to even detect that two separate objects are present.

The main limitation of this study is that phantoms were used. Although this may show the technical limits of the machine, it does not fully apply to patient care. The phantoms do not move and have high contrast markers for measurement. Obviously this is not the case with patients. Longer scan times in patients greatly increases the radiation exposure and the risk of movement which may negate the increase in spatial resolution seen with longer scan times. It must be kept in mind that even the poorest spatial resolution according to the strict manufacturer's guidelines was 0.806 mm. This resolution may be perfectly adequate for craniofacial imaging in orthodontics and the benefits of a shorter scan time and less patient movement may outweigh the poorer resolution. Another limitation to this study may be that the high contrast markers and line pairs were clearly seen on the images of the phantoms, but there is a range of contrast in human patients which makes landmark identification more difficult.

Conclusions:

The results from the present study clearly indicate that the commercially available CBCT is acceptable for linear measurements in all planes of space. The measurements differed from the exact digital caliper measurements by less than 0.1 mm which was determined to be clinically insignificant in most situations. There was

no setting that was better than the others for linear measurement accuracy and the measurements were accurate in all areas of the field of view. Spatial resolution can be improved by selecting the appropriate image setting with smaller voxel sizes and longer scan times providing higher spatial resolutions. However, one must be cognizant of the fact that longer scan times in human patients may be detrimental due to increased radiation exposure and patient movement.

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TABLE 1.--Mean Absolute Differences Between CBCT Measurements and Direct Measurements of the CIC-Phantom

Image Setting	Height		Width		Depth	
	Absolute Difference (mm)	CBCT minus Direct (mm)	Absolute Difference (mm)	CBCT minus Direct (mm)	Absolute Difference (mm)	CBCT minus Direct (mm)
13cm, 40sec, 0.4mm Voxel	0.072 +/- 0.049	-0.015 +/- 0.087	0.074 +/- 0.051	-0.014 +/- 0.090	0.082 +/- 0.066	-0.059 +/- 0.088
13cm, 20sec, 0.4mm Voxel	0.056 +/- 0.042	-0.013 +/- 0.069	0.050 +/- 0.042	-0.005 +/- 0.066	0.078 +/- 0.071	-0.023 +/- 0.104
13cm, 10sec, 0.4mm Voxel	0.067 +/- 0.053	-0.020 +/- 0.084	0.050 +/- 0.045	-0.024 +/- 0.063	0.064 +/- 0.055	-0.036 +/- 0.077
13cm, 20sec, 0.3mm Voxel	0.067 +/- 0.054	-0.039 +/- 0.077	0.046 +/- 0.035	-0.011 +/- 0.057	0.063 +/- 0.048	-0.044 +/- 0.067
13cm, 40sec, 0.25mm Voxel	0.060 +/- 0.062	-0.034 +/- 0.080	0.049 +/- 0.037	0.007 +/- 0.062	0.074 +/- 0.054	-0.042 +/- 0.082
8cm, 20sec, 0.4mm Voxel	0.082 +/- 0.063	-0.020 +/- 0.103	0.046 +/- 0.036	-0.004 +/- 0.058	0.071 +/- 0.056	-0.032 +/- 0.085
6cm, 20sec, 0.4mm Voxel Denex Mandibular	0.085 +/- 0.088	-0.019 +/- 0.124	0.047 +/- 0.040	-0.020 +/- 0.059	0.060 +/- 0.052	-0.029 +/- 0.074
6cm, 20sec, 0.4mm Voxel Denex Maxillary	0.071 +/- 0.066	-0.025 +/- 0.096	0.051 +/- 0.040	-0.029 +/- 0.059	0.068 +/- 0.045	-0.051 +/- 0.064
6cm, 10sec, 0.4mm Voxel	0.065 +/- 0.065	0.008 +/- 0.093	0.053 +/- 0.043	-0.035 +/- 0.059	0.063 +/- 0.047	-0.033 +/- 0.072
6cm, 10sec, 0.3mm Voxel	0.061 +/- 0.041	-0.031 +/- 0.070	0.055 +/- 0.045	-0.033 +/- 0.063	0.055 +/- 0.047	-0.024 +/- 0.068
6cm, 40sec, 0.2mm Voxel Mandibular	0.058 +/- 0.059	-0.012 +/- 0.084	0.059 +/- 0.040	-0.046 +/- 0.054	0.058 +/- 0.034	-0.050 +/- 0.046
6cm, 40sec, 0.2mm Voxel Maxillary	0.073 +/- 0.063	-0.036 +/- 0.091	0.070 +/- 0.042	-0.062 +/- 0.054	0.061 +/- 0.031	-0.046 +/- 0.052
Average	0.068	-0.021	0.054	-0.023	0.066	-0.039
Standard Deviation	0.009	0.013	0.009	0.019	0.008	0.011

ANOVA p = 0.964

TABLE 2.--Mean Absolute Differences Between CBCT Measurements and Direct Measurements of the CIC-Phantom Analyzed by Thirds

	Height			Width			Depth		
Image Setting	**Top**	**Middle**	**Bottom**	**Left**	**Middle**	**Right**	**Front**	**Middle**	**Back**
13cm, 40sec, 0.4mm Voxel	0.037 +/- 0.040	0.053 +/- 0.058	0.010 +/- 0.044	0.072 +/- 0.048	0.067 +/- 0.055	0.081 +/- 0.050	0.108 +/- 0.068	0.090 +/- 0.078	0.060 +/- 0.035
13cm, 20sec, 0.4mm Voxel	0.037 +/- 0.039	0.087 +/- 0.056	0.040 +/- 0.020	0.045 +/- 0.049	0.027 +/- 0.042	0.038 +/- 0.033	0.058 +/- 0.054	0.063 +/- 0.102	0.090 +/- 0.048
13cm, 10sec, 0.4mm Voxel	0.020 +/- 0.030	0.030 +/- 0.056	0.060 +/- 0.058	0.028 +/- 0.046	0.050 +/- 0.048	0.043 +/- 0.041	0.042 +/- 0.067	0.073 +/- 0.065	0.047 +/- 0.031
13cm, 20sec, 0.3mm Voxel	0.028 +/- 0.025	0.027 +/- 0.073	0.017 +/- 0.041	0.040 +/- 0.019	0.017 +/- 0.046	0.050 +/- 0.039	0.052 +/- 0.043	0.015 +/- 0.070	0.035 +/- 0.024
13cm, 40sec, 0.25mm Voxel	0.032 +/- 0.036	0.015 +/- 0.080	0.022 +/- 0.059	0.047 +/- 0.032	0.067 +/- 0.037	0.047 +/- 0.045	0.070 +/- 0.044	0.028 +/- 0.073	0.085 +/- 0.045
8cm, 20sec, 0.4mm Voxel	0.092 +/- 0.036	0.060 +/- 0.084	0.052 +/- 0.029	0.045 +/- 0.031	0.033 +/- 0.046	0.040 +/- 0.029	0.108 +/- 0.064	0.047 +/- 0.058	0.113 +/- 0.050
6cm, 20sec, 0.4mm Voxel – Denex Mand.	0.112 +/- 0.104	0.012 +/- 0.114	0.068 +/- 0.038	0.068 +/- 0.030	0.023 +/- 0.048	0.057 +/- 0.040	0.075 +/- 0.044	0.080 +/- 0.068	0.060 +/- 0.034
6cm, 20sec, 0.4mm Voxel – Denex Max.	0.088 +/- 0.088	0.028 +/- 0.076	0.052 +/- 0.024	0.022 +/- 0.030	0.050 +/- 0.035	0.066 +/- 0.049	0.108 +/- 0.045	0.073 +/- 0.058	0.053 +/- 0.032
6cm, 10sec, 0.4mm Voxel	0.055 +/- 0.019	0.028 +/- 0.093	0.035 +/- 0.021	0.035 +/- 0.033	0.057 +/- 0.056	0.057 +/- 0.029	0.058 +/- 0.040	0.040 +/- 0.057	0.110 +/- 0.047
6cm, 10sec, 0.3mm Voxel	0.068 +/- 0.040	0.032 +/- 0.045	0.055 +/- 0.044	0.040 +/- 0.019	0.037 +/- 0.065	0.071 +/- 0.039	0.033 +/- 0.047	0.028 +/- 0.041	0.070 +/- 0.050
6cm, 40sec, 0.2mm Voxel - Mandibular	0.042 +/- 0.043	0.033 +/- 0.073	0.025 +/- 0.024	0.062 +/- 0.030	0.018 +/- 0.045	0.060 +/- 0.044	0.045 +/- 0.029	0.060 +/- 0.031	0.015 +/- 0.042
6cm, 40sec, 0.2mm Voxel - Maxillary	0.092 +/- 0.050	0.035 +/- 0.081	0.018 +/- 0.020	0.070 +/- 0.043	0.060 +/- 0.045	0.079 +/- 0.041	0.047 +/- 0.028	0.093 +/- 0.032	0.037 +/- 0.034
Average for Each Third	0.059	0.037	0.038	0.048	0.042	0.057	0.067	0.058	0.065
Standard Deviation	0.031	0.021	0.019	0.017	0.019	0.015	0.027	0.026	0.030

ANOVA p = 0.259

TABLE 3.--Paired Two Sample T-Test for Comparing CBCT Measurements to Direct Measurements

	CBCT Measurements	**Direct Measurements**
Mean (mm)	5.12904351	5.158349515
Variance	0.026976286	0.024288718
Observations	927	927
Pearson Correlation	0.895953493	
df	926	
t Stat	-12.14551714	
P(T<=t) two-tail	1.32926 E -31	
t Critical two-tail	1.962529084	

TABLE 4.--Average Resolution of the C-Phantom Assigned by 30 Evaluators

Image Setting	Clear Separation of 4 Lines (mm)	Pattern of 4 Lines (mm)	Ranking by Clear Separation	Ranking by Pattern
13cm,40sec,0.4mm Voxel	0.823	0.673	7	7
13cm,20sec,0.4mm Voxel	0.807	0.693	6	10
13cm,10sec,0.4mm Voxel	0.860	0.704	12	12
13cm,20sec,0.3mm Voxel	0.848	0.697	11	11
13cm,40sec,0.25mm Voxel	0.804	0.666	5	5
8cm,20sec,0.4mm Voxel	0.838	0.676	9 - Tie	8
6cm,20sec,0.4mm Voxel Denex Mandibular	0.790	0.659	4	4
6cm, 20sec, 0.4mm Voxel Denex Maxillary	0.785	0.657	3	3
6cm,10sec,0.4mm Voxel	0.832	0.668	8	6
6cm,10sec,0.3mm Voxel	0.838	0.683	9 - Tie	9
6cm,40sec,0.2mm Voxel Mandibular	0.622	0.398	1	1
6cm,40sec,0.2mm Voxel Maxillary	0.638	0.405	2	2

R1 to R2 Intra-Class Correlation	0.782	0.914

% Variation Explained by:	Clear Separation of 4 Lines (R^2)	Pattern of 4 Lines (R^2)
Image Size	22.3	23.2
Seconds	43.9	39.4
Voxel Size	52.1	57.8
Seconds and Voxel Size	60.1	62.1

TABLE 5.--Intra-operator Measurement Reliability by Standard Deviations

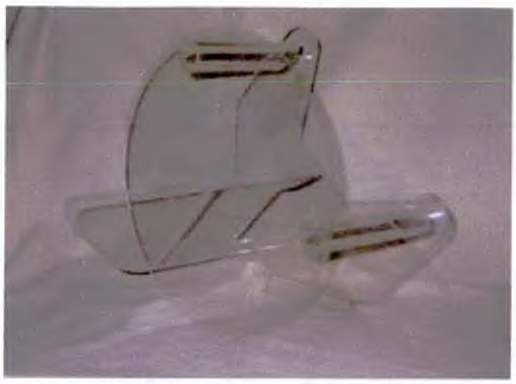
Image Setting	Height		Width		Depth	
	Std Dev Avg (mm)	95% of Measures	Std Dev Avg (mm)	95% of Measures	Std Dev Avg (mm)	95% of Measures
13cm, 40sec, 0.4mm Voxel	0.052	+/- 0.104	0.065	+/- 0.130	0.072	+/- 0.144
13cm, 20sec, 0.4mm Voxel	0.052	+/- 0.104	0.061	+/- 0.122	0.057	+/- 0.114
13cm, 10sec, 0.4mm Voxel	0.047	+/- 0.094	0.048	+/- 0.096	0.055	+/- 0.110
13cm, 20sec, 0.3mm Voxel	0.036	+/- 0.072	0.052	+/- 0.104	0.045	+/- 0.090
13cm, 40sec, 0.25mm Voxel	0.047	+/- 0.094	0.051	+/- 0.102	0.056	+/- 0.112
8cm, 20sec, 0.4mm Voxel	0.042	+/- 0.084	0.060	+/- 0.120	0.059	+/- 0.118
6cm, 20sec, 0.4mm Voxel Denex Mandibular	0.033	+/- 0.066	0.046	+/- 0.092	0.039	+/- 0.078
6cm, 20sec, 0.4mm Voxel Denex Maxillary	0.040	+/- 0.080	0.032	+/- 0.064	0.046	+/- 0.092
6cm, 10sec, 0.4mm Voxel	0.029	+/- 0.058	0.038	+/- 0.076	0.057	+/- 0.114
6cm, 10sec, 0.3mm Voxel	0.037	+/- 0.074	0.038	+/- 0.076	0.051	+/- 0.102
6cm, 40sec, 0.2mm Voxel Mandibular	0.017	+/- 0.034	0.041	+/- 0.082	0.043	+/- 0.086
6cm, 40sec, 0.2mm Voxel Maxillary	0.025	+/- 0.050	0.041	+/- 0.082	0.040	+/- 0.080
Direct Measurement (Caliper)	0.047	+/- 0.094	0.044	+/- 0.088	0.042	+/- 0.084

TABLE 6.--i-CAT Image Setting Information

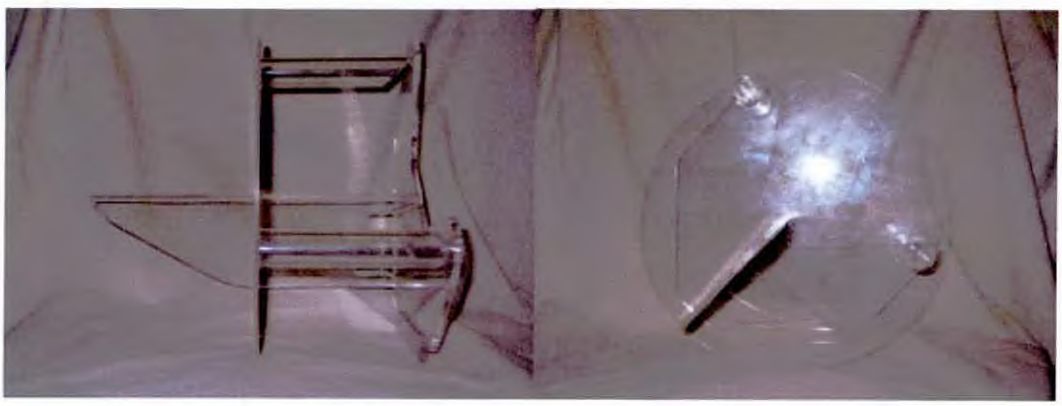
Requested Size (cm)	Actual Size (cm)			Scan Time (sec)*	Voxel Size (mm)*	Exposure Time (sec)*	mAs*	Raw Images Collected	Primary Reconstruction DICOM 3 Axial Slices
	Height	Width	Depth						
13	12.81	16.02	16.01	40	0.4	7.2	47	599	323
13	12.82	15.99	16.00	20	0.4	3.6	24	306	323
13	12.82	16.02	16.03	10	0.4	1.8	12	160	323
13	12.82	16.03	16.05	20	0.3	3.6	24	306	430
13	12.82	16.06	16.05	40	0.25	7.2	47	599	516
8	7.88	16.03	16.05	20	0.4	3.6	24	306	200
6 Denex Mand	5.45	16.05	16.00	20	0.4	3.6	24	599	138
6 Denex Max	5.44	16.00	16.02	20	0.4	3.6	24	599	138
6	5.46	16.03	16.04	10	0.4	1.8	12	160	138
6	5.44	16.05	16.02	10	0.3	1.8	12	160	183
6 Mandibular	5.47	16.03	16.02	40	0.2	7.2	47	306	277
6 Maxillary	5.48	16.04	16.04	40	0.2	7.2	47	306	277

* = Manufacturer specifications

All Images Collected at 120 kVp and 5mA



Angle View



Front View Side View

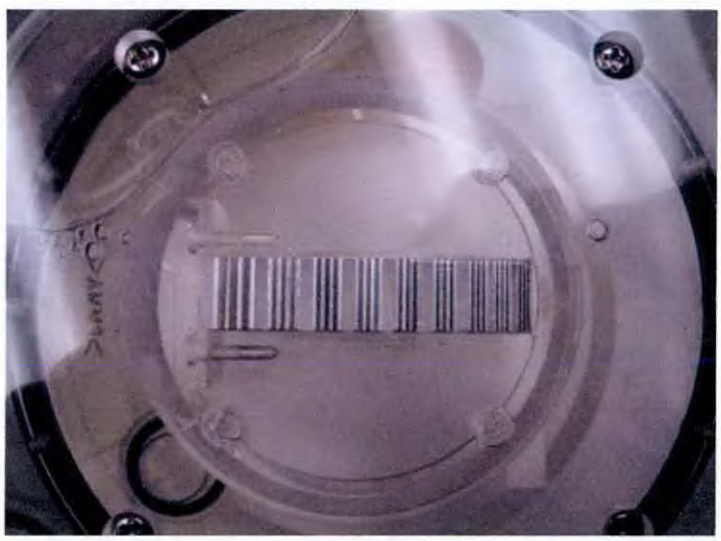
Figure 1. Multiple views of the CIC-Phantom.



Figure 2. Relative size of the 0.3 mm measurement markers compared to a dime.



Side View



Top View

Figure 3. Multiple views of the C-Phantom illustrating the high contrast line pairs.

APPENDIX 1

Raw Data: CIC-Phantom

TABLE 7.--Measurement Accuracy of a 13 cm, 40 sec, 0.4 mm Voxel Scan for Height

Third	Points	T1	T2	T3	CB Mean	SD	Abs Diff	CBCT-DIR	DIR Mean
Top	10 to 11	5.2	5.2	5.1	5.167	0.058	0.043	0.043	5.123
Top	9 to 10	5	5.1	5	5.033	0.058	0.077	-0.077	5.110
Top	8 to 9	5.2	5.1	5.1	5.133	0.058	0.023	-0.023	5.157
Top	7 to 8	5	5.1	5	5.033	0.058	0.090	-0.090	5.123
Top	6 to 7	5.2	5.2	5.2	5.200	0.000	0.033	0.033	5.167
Top	5 to 6	5.1	5	5	5.033	0.058	0.133	-0.133	5.167
Top	4 to 5	5	5.1	5	5.033	0.058	0.030	-0.030	5.063
Middle	3 to 4	5.2	5.1	5.1	5.133	0.058	0.083	-0.083	5.217
Middle	2 to 3	5	5	5	5.000	0.000	0.107	-0.107	5.107
Middle	1 to 2	5.1	5.2	5.2	5.167	0.058	0.037	-0.037	5.203
Middle	0 to 1	5.2	5.2	5.1	5.167	0.058	0.180	0.180	4.987
Middle	0 to -1	5	5	5	5.000	0.000	0.170	-0.170	5.170
Middle	-1 to -2	5.2	5.2	5.2	5.200	0.000	0.053	0.053	5.147
Middle	-2 to -3	5.2	5.1	5.2	5.167	0.058	0.113	0.113	5.053
Middle	-3 to -4	5.3	5.1	5.2	5.200	0.100	0.023	-0.023	5.223
Bottom	-4 to -5	5.1	5.2	5.2	5.167	0.058	0.017	0.017	5.150
Bottom	-5 to -6	5.2	5.1	5.2	5.167	0.058	0.103	0.103	5.063
Bottom	-6 to -7	5.1	5.2	5	5.100	0.100	0.100	-0.100	5.200
Bottom	-7 to -8	5.2	5.2	5.1	5.167	0.058	0.020	0.020	5.147
Bottom	-8 to -9	5.3	5.2	5.2	5.233	0.058	0.070	0.070	5.163
Bottom	-9 to -10	5	5.1	5	5.033	0.058	0.040	-0.040	5.073
Bottom	-10 to -11	5.2	5.3	5.3	5.267	0.058	0.053	0.053	5.213
Bottom	-11 to -12	5	4.9	4.9	4.933	0.058	0.130	-0.130	5.063
Bottom	-12 to -13	5.3	5.2	5.3	5.267	0.058	0.003	0.003	5.263
					Overall Avg		0.072	-0.015	
					Top Avg		0.037		
					Middle Avg		0.053		
					Bottom Avg		0.010		
					Overall SD		0.049	0.087	
					Top SD		0.040		
					Middle SD		0.058		
					Bottom SD		0.044		

TABLE 8.--Measurement Accuracy of a 13 cm, 40 sec, 0.4 mm Voxel Scan for Width

Third	Points	T1	T2	T3	CB Mean	SD	Abs Diff	CBCT-DIR	DIR Mean
Left	15 to 16	5.1	5	5.1	5.067	0.058	0.020	-0.020	5.087
Left	14 to 15	5.2	5.1	5.3	5.200	0.100	0.003	0.003	5.197
Left	13 to 14	5.2	5.4	5.2	5.267	0.115	0.147	0.147	5.120
Left	12 to 13	5.3	5.3	5.2	5.267	0.058	0.053	0.053	5.213
Left	11 to 12	5.2	5.3	5.2	5.233	0.058	0.103	0.103	5.130
Left	10 to 11	5.3	5.3	5.2	5.267	0.058	0.063	0.063	5.203
Left	9 to 10	5.2	5.1	5.1	5.133	0.058	0.030	-0.030	5.163
Left	8 to 9	5.1	5.2	5.3	5.200	0.100	0.020	0.020	5.180
Left	7 to 8	5.1	5.3	5.1	5.167	0.115	0.017	0.017	5.150
Left	6 to 7	5.1	5.1	5.1	5.100	0.000	0.040	0.040	5.060
Left	5 to 6	5.1	5.1	5.1	5.100	0.000	0.123	-0.123	5.223
Middle	4 to 5	5.3	5.2	5.2	5.233	0.058	0.060	0.060	5.173
Middle	3 to 4	5.1	5.1	5	5.067	0.058	0.120	0.120	4.947
Middle	2 to 3	5.6	5.7	5.6	5.633	0.058	0.003	-0.003	5.637
Middle	1 to 2	5	4.9	4.9	4.933	0.058	0.080	0.080	4.853
Middle	0 to 1	4.3	4.4	4.4	4.367	0.058	0.163	-0.163	4.530
Middle	0 to -1	5.9	6	6	5.967	0.058	0.033	-0.033	6.000
Middle	-1 to -2	5.2	5.1	5.2	5.167	0.058	0.183	-0.183	5.350
Middle	-2 to -3	5	5	5.1	5.033	0.058	0.080	-0.080	5.113
Middle	-3 to -4	5.2	5	5.3	5.167	0.153	0.067	0.067	5.100
Middle	-4 to -5	5	5	5.1	5.033	0.058	0.073	-0.073	5.107
Right	-5 to -6	4.9	5.1	4.8	4.933	0.153	0.143	-0.143	5.077
Right	-6 to -7	5.2	5.1	5.1	5.133	0.058	0.053	-0.053	5.187
Right	-7 to -8	5.2	5.3	5.3	5.267	0.058	0.037	0.037	5.230
Right	-8 to -9	5.2	5.2	5.2	5.200	0.000	0.083	0.083	5.117
Right	-9 to -10	5.2	5.1	5.2	5.167	0.058	0.010	-0.010	5.177
Right	-10 to -11	5.1	5.1	5	5.067	0.058	0.033	-0.033	5.100
Right	-11 to -12	5.2	5.1	5.1	5.133	0.058	0.113	-0.113	5.247
Right	-12 to -13	5.2	5.2	5.1	5.167	0.058	0.107	-0.107	5.273
Right	-13 to -14	5	5	5.1	5.033	0.058	0.150	-0.150	5.183

Overall Avg	0.074	-0.014
Left Avg	0.072	
Middle Avg	0.067	
Right Avg	0.081	
Overall SD	0.051	0.090
Left SD	0.048	
Middle SD	0.055	
Right SD	0.050	

TABLE 9.--Measurement Accuracy of a 13 cm, 40 sec, 0.4 mm Voxel Scan for Depth

Third	Points	T1	T2	T3	CB Mean	SD	Abs Diff	CBCT-DIR	DIR Mean
Front	14 to 15	5.2	5.2	5.1	5.167	0.058	0.083	-0.083	5.250
Front	13 to 14	5	5.1	5.1	5.067	0.058	0.057	-0.057	5.123
Front	12 to 13	5	5.2	5	5.067	0.115	0.070	-0.070	5.137
Front	11 to 12	5	4.9	5.1	5.000	0.100	0.190	-0.190	5.190
Front	10 to 11	5.1	5.1	5.3	5.167	0.115	0.093	-0.093	5.260
Front	9 to 10	4.9	5	5	4.967	0.058	0.183	-0.183	5.150
Front	8 to 9	5	5.2	5	5.067	0.115	0.000	0.000	5.067
Front	7 to 8	4.9	5	5	4.967	0.058	0.217	-0.217	5.183
Front	6 to 7	5.2	5.1	5.2	5.167	0.058	0.100	-0.100	5.267
Front	5 to 6	4.8	5	4.9	4.900	0.100	0.133	-0.133	5.033
Middle	4 to 5	4.8	5	5	4.933	0.115	0.103	-0.103	5.037
Middle	3 to 4	5.3	5.3	5.2	5.267	0.058	0.027	-0.027	5.293
Middle	2 to 3	4.9	4.9	4.9	4.900	0.000	0.147	-0.147	5.047
Middle	1 to 2	5.1	5.2	5	5.100	0.100	0.060	-0.060	5.160
Middle	0 to 1	5.3	5.2	5.2	5.233	0.058	0.220	0.220	5.013
Middle	0 to -1	4.9	4.9	4.9	4.900	0.000	0.207	-0.207	5.107
Middle	-1 to -2	5.1	5.2	5.3	5.200	0.100	0.033	-0.033	5.233
Middle	-2 to -3	5.1	5	5.1	5.067	0.058	0.017	0.017	5.050
Middle	-3 to -4	5.2	5.3	5.2	5.233	0.058	0.003	0.003	5.230
Middle	-4 to -5	5.1	4.9	5.1	5.033	0.115	0.077	-0.077	5.110
Back	-5 to -6	5.2	5.2	5.2	5.200	0.000	0.057	0.057	5.143
Back	-6 to -7	5.2	5.2	5.3	5.233	0.058	0.050	0.050	5.183
Back	-7 to -8	5	5.1	5.1	5.067	0.058	0.090	-0.090	5.157
Back	-8 to -9	5.1	5.2	5.1	5.133	0.058	0.003	-0.003	5.137
Back	-9 to -10	5.3	5.2	5.3	5.267	0.058	0.003	0.003	5.263
Back	-10 to -11	5	4.9	5.1	5.000	0.100	0.083	-0.083	5.083
Back	-11 to -12	5.2	5.3	5.3	5.267	0.058	0.003	-0.003	5.270
Back	-12 to -13	5	5.2	5	5.067	0.115	0.017	-0.017	5.083
Back	-13 to -14	5.2	5.1	5	5.100	0.100	0.090	-0.090	5.190
Back	-14 to -15	5	5.1	5.1	5.067	0.058	0.063	-0.063	5.130
Back	-15 to -16	5.3	5.2	5.2	5.233	0.058	0.063	-0.063	5.297
					Overall Avg		0.082	-0.059	
					Front Avg		0.108		
					Middle Avg		0.090		
					Back Avg		0.060		
					Overall SD		0.066	0.088	
					Front SD		0.068		
					Middle SD		0.078		
					Back SD		0.035		

TABLE 10.--Measurement Accuracy of a 13 cm, 20 sec, 0.4 mm Voxel Scan for Height

Third	Points	T1	T2	T3	CB Mean	SD	Abs Diff	CBCT-DIR	DIR Mean
Top	10 to 11	5.2	5.2	5.1	5.167	0.058	0.043	0.043	5.123
Top	9 to 10	5.2	5.1	5.1	5.133	0.058	0.023	0.023	5.110
Top	8 to 9	5.2	5.1	5.2	5.167	0.058	0.010	0.010	5.157
Top	7 to 8	5	5	5.1	5.033	0.058	0.090	-0.090	5.123
Top	6 to 7	5.2	5.1	5.2	5.167	0.058	0.000	0.000	5.167
Top	5 to 6	5.1	5.1	5	5.067	0.058	0.100	-0.100	5.167
Top	4 to 5	5	5.1	5	5.033	0.058	0.030	-0.030	5.063
Middle	3 to 4	5	5.1	5.2	5.100	0.100	0.117	-0.117	5.217
Middle	2 to 3	5	5.1	5.1	5.067	0.058	0.040	-0.040	5.107
Middle	1 to 2	5.1	5.1	5.1	5.100	0.000	0.103	-0.103	5.203
Middle	0 to 1	5.1	5.2	5.2	5.167	0.058	0.180	0.180	4.987
Middle	0 to -1	5.1	5.1	5	5.067	0.058	0.103	-0.103	5.170
Middle	-1 to -2	5.1	5.2	5.2	5.167	0.058	0.020	0.020	5.147
Middle	-2 to -3	5.1	5	5	5.033	0.058	0.020	-0.020	5.053
Middle	-3 to -4	5.2	5.2	5.1	5.167	0.058	0.057	-0.057	5.223
Bottom	-4 to -5	5.1	5.2	5.1	5.133	0.058	0.017	-0.017	5.150
Bottom	-5 to -6	5.1	5.2	5.1	5.133	0.058	0.070	0.070	5.063
Bottom	-6 to -7	5.3	5.2	5.2	5.233	0.058	0.033	0.033	5.200
Bottom	-7 to -8	5.2	5.2	5.1	5.167	0.058	0.020	0.020	5.147
Bottom	-8 to -9	5.2	5.3	5.2	5.233	0.058	0.070	0.070	5.163
Bottom	-9 to -10	5.1	5	5	5.033	0.058	0.040	-0.040	5.073
Bottom	-10 to -11	5.2	5.1	5.2	5.167	0.058	0.047	-0.047	5.213
Bottom	-11 to -12	5.1	5.1	5.1	5.100	0.000	0.037	0.037	5.063
Bottom	-12 to -13	5.2	5.2	5.2	5.200	0.000	0.063	-0.063	5.263
					Overall Avg		0.056	-0.013	
					Top Avg		0.037		
					Middle Avg		0.087		
					Bottom Avg		0.040		
					Overall SD		0.042	0.069	
					Top SD		0.039		
					Middle SD		0.056		
					Bottom SD		0.020		

TABLE 11.--Measurement Accuracy of a 13 cm, 20 sec, 0.4 mm Voxel Scan for Width

Third	Points	T1	T2	T3	CB Mean	SD	Abs Diff	CBCT-DIR	DIR Mean
Left	15 to 16	5.1	5.1	5.2	5.133	0.058	0.047	0.047	5.087
Left	14 to 15	5.3	5.4	5.3	5.333	0.058	0.137	0.137	5.197
Left	13 to 14	5	5.2	5.2	5.133	0.115	0.013	0.013	5.120
Left	12 to 13	5.2	5.2	5.2	5.200	0.000	0.013	-0.013	5.213
Left	11 to 12	5	5.2	5.2	5.133	0.115	0.003	0.003	5.130
Left	10 to 11	5.1	5.3	5.2	5.200	0.100	0.003	-0.003	5.203
Left	9 to 10	5	5.2	5.2	5.133	0.115	0.030	-0.030	5.163
Left	8 to 9	5.2	5.2	5.1	5.167	0.058	0.013	-0.013	5.180
Left	7 to 8	5	5.1	5	5.033	0.058	0.117	-0.117	5.150
Left	6 to 7	5.1	5.2	5.2	5.167	0.058	0.107	0.107	5.060
Left	5 to 6	5.3	5.3	5.2	5.267	0.058	0.043	0.043	5.223
Middle	4 to 5	5.3	5.1	5.2	5.200	0.100	0.027	0.027	5.173
Middle	3 to 4	5	5	5	5.000	0.000	0.053	0.053	4.947
Middle	2 to 3	5.6	5.7	5.6	5.633	0.058	0.003	-0.003	5.637
Middle	1 to 2	4.8	4.7	4.7	4.733	0.058	0.120	-0.120	4.853
Middle	0 to 1	4.5	4.4	4.4	4.433	0.058	0.097	-0.097	4.530
Middle	0 to -1	5.9	5.9	6	5.933	0.058	0.067	-0.067	6.000
Middle	-1 to -2	5.3	5.3	5.3	5.300	0.000	0.050	-0.050	5.350
Middle	-2 to -3	5.1	5	5.1	5.067	0.058	0.047	-0.047	5.113
Middle	-3 to -4	5.2	5.2	5.3	5.233	0.058	0.133	0.133	5.100
Middle	-4 to -5	5.1	5.2	5.1	5.133	0.058	0.027	0.027	5.107
Right	-5 to -6	5	5.1	5	5.033	0.058	0.043	-0.043	5.077
Right	-6 to -7	5.2	5.2	5.1	5.167	0.058	0.020	-0.020	5.187
Right	-7 to -8	5.2	5.3	5.2	5.233	0.058	0.003	0.003	5.230
Right	-8 to -9	5.2	5.1	5.1	5.133	0.058	0.017	0.017	5.117
Right	-9 to -10	5.3	5.2	5.2	5.233	0.058	0.057	0.057	5.177
Right	-10 to -11	5	5	5.1	5.033	0.058	0.067	-0.067	5.100
Right	-11 to -12	5.2	5.2	5.3	5.233	0.058	0.013	-0.013	5.247
Right	-12 to -13	5.1	5.2	5.2	5.167	0.058	0.107	-0.107	5.273
Right	-13 to -14	5.2	5.2	5.1	5.167	0.058	0.017	-0.017	5.183
					Overall Avg		0.050	-0.005	
					Left Avg		0.045		
					Middle Avg		0.027		
					Right Avg		0.038		
					Overall SD		0.042	0.066	
					Left SD		0.049		
					Middle SD		0.042		
					Right SD		0.033		

TABLE 12.--Measurement Accuracy of a 13 cm, 20 sec, 0.4 mm Voxel Scan for Depth

Third	Points	T1	T2	T3	CB Mean	SD	Abs Diff	CBCT-DIR	DIR Mean
Front	14 to 15	5.2	5.1	5.2	5.167	0.058	0.083	-0.083	5.250
Front	13 to 14	5.1	5.1	5	5.067	0.058	0.057	-0.057	5.123
Front	12 to 13	4.9	5.1	4.9	4.967	0.115	0.170	-0.170	5.137
Front	11 to 12	5	5	5.1	5.033	0.058	0.157	-0.157	5.190
Front	10 to 11	5.2	5.2	5.2	5.200	0.000	0.060	-0.060	5.260
Front	9 to 10	5	5.2	5.2	5.133	0.115	0.017	-0.017	5.150
Front	8 to 9	5	5.1	5	5.033	0.058	0.033	-0.033	5.067
Front	7 to 8	5	5.1	5.1	5.067	0.058	0.117	-0.117	5.183
Front	6 to 7	5.2	5.2	5.3	5.233	0.058	0.033	-0.033	5.267
Front	5 to 6	4.9	5.1	5	5.000	0.100	0.033	-0.033	5.033
Middle	4 to 5	5	4.9	5	4.967	0.058	0.070	-0.070	5.037
Middle	3 to 4	5.2	5.3	5.3	5.267	0.058	0.027	-0.027	5.293
Middle	2 to 3	5	5.1	5	5.033	0.058	0.013	-0.013	5.047
Middle	1 to 2	5	5	5.1	5.033	0.058	0.127	-0.127	5.160
Middle	0 to 1	5.3	5.3	5.3	5.300	0.000	0.287	0.287	5.013
Middle	0 to -1	4.9	4.8	4.8	4.833	0.058	0.273	-0.273	5.107
Middle	-1 to -2	5.2	5.3	5.4	5.300	0.100	0.067	0.067	5.233
Middle	-2 to -3	5.1	5.1	5.1	5.100	0.000	0.050	0.050	5.050
Middle	-3 to -4	5.2	5.3	5.2	5.233	0.058	0.003	0.003	5.230
Middle	-4 to -5	5.2	5.2	5.1	5.167	0.058	0.057	0.057	5.110
Back	-5 to -6	5	5.2	5.2	5.133	0.115	0.010	-0.010	5.143
Back	-6 to -7	5.3	5.3	5.3	5.300	0.000	0.117	0.117	5.183
Back	-7 to -8	5	5.2	5	5.067	0.115	0.090	-0.090	5.157
Back	-8 to -9	5.2	5.2	5.2	5.200	0.000	0.063	0.063	5.137
Back	-9 to -10	5.2	5.2	5.3	5.233	0.058	0.030	-0.030	5.263
Back	-10 to -11	5	5	5.1	5.033	0.058	0.050	-0.050	5.083
Back	-11 to -12	5.2	5.2	5.2	5.200	0.000	0.070	-0.070	5.270
Back	-12 to -13	5.1	5	5	5.033	0.058	0.050	-0.050	5.083
Back	-13 to -14	5.2	5.2	5.3	5.233	0.058	0.043	0.043	5.190
Back	-14 to -15	5.1	5.1	5.2	5.133	0.058	0.003	0.003	5.130
Back	-15 to -16	5.4	5.5	5.5	5.467	0.058	0.170	0.170	5.297
					Overall Avg		0.078	-0.023	
					Front Avg		0.058		
					Middle Avg		0.063		
					Back Avg		0.090		
					Overall SD		0.071	0.104	
					Front SD		0.054		
					Middle SD		0.102		
					Back SD		0.048		

TABLE 13.--Measurement Accuracy of a 13 cm, 10 sec, 0.4 mm Voxel Scan for Height

Third	Points	T1	T2	T3	CB Mean	SD	Abs Diff	CBCT-DIR	DIR Mean
Top	10 to 11	5.1	5.1	5.2	5.133	0.058	0.010	0.010	5.123
Top	9 to 10	5.1	5.2	5.1	5.133	0.058	0.023	0.023	5.110
Top	8 to 9	5.1	5.1	5.1	5.100	0.000	0.057	-0.057	5.157
Top	7 to 8	5.1	5.1	5	5.067	0.058	0.057	-0.057	5.123
Top	6 to 7	5.2	5.2	5.2	5.200	0.000	0.033	0.033	5.167
Top	5 to 6	5.1	5.1	5	5.067	0.058	0.100	-0.100	5.167
Top	4 to 5	5.1	5	5	5.033	0.058	0.030	-0.030	5.063
Middle	3 to 4	5.2	5.2	5.1	5.167	0.058	0.050	-0.050	5.217
Middle	2 to 3	5	5	4.9	4.967	0.058	0.140	-0.140	5.107
Middle	1 to 2	5.1	5.1	5.1	5.100	0.000	0.103	-0.103	5.203
Middle	0 to 1	5.1	5.2	5.2	5.167	0.058	0.180	0.180	4.987
Middle	0 to -1	5.1	5	5	5.033	0.058	0.137	-0.137	5.170
Middle	-1 to -2	5.2	5.1	5.3	5.200	0.100	0.053	0.053	5.147
Middle	-2 to -3	5.2	5.1	5.1	5.133	0.058	0.080	0.080	5.053
Middle	-3 to -4	5.2	5.3	5.2	5.233	0.058	0.010	0.010	5.223
Bottom	-4 to -5	5.1	5.2	5.1	5.133	0.058	0.017	-0.017	5.150
Bottom	-5 to -6	5	5.1	5.1	5.067	0.058	0.003	0.003	5.063
Bottom	-6 to -7	5	5	5.1	5.033	0.058	0.167	-0.167	5.200
Bottom	-7 to -8	5.2	5.1	5.1	5.133	0.058	0.013	-0.013	5.147
Bottom	-8 to -9	5.1	5.1	5.1	5.100	0.000	0.063	-0.063	5.163
Bottom	-9 to -10	5.1	5.2	5.1	5.133	0.058	0.060	0.060	5.073
Bottom	-10 to -11	5.1	5.1	5.1	5.100	0.000	0.113	-0.113	5.213
Bottom	-11 to -12	5.1	5	5.1	5.067	0.058	0.003	0.003	5.063
Bottom	-12 to -13	5.4	5.3	5.4	5.367	0.058	0.103	0.103	5.263
					Overall Avg		0.067	-0.020	
					Top Avg		0.020		
					Middle Avg		0.030		
					Bottom Avg		0.060		
					Overall SD		0.053	0.084	
					Top SD		0.030		
					Middle SD		0.056		
					Bottom SD		0.058		

TABLE 14.--Measurement Accuracy of a 13 cm, 10 sec, 0.4 mm Voxel Scan for Width

Third	Points	T1	T2	T3	CB Mean	SD	Abs Diff	CBCT-DIR	DIR Mean
Left	15 to 16	5.2	5.1	5.1	5.133	0.058	0.047	0.047	5.087
Left	14 to 15	5.2	5.3	5.2	5.233	0.058	0.037	0.037	5.197
Left	13 to 14	5.2	5.1	5.1	5.133	0.058	0.013	0.013	5.120
Left	12 to 13	5.2	5.2	5.2	5.200	0.000	0.013	-0.013	5.213
Left	11 to 12	5.2	5.3	5.2	5.233	0.058	0.103	0.103	5.130
Left	10 to 11	5.2	5.2	5.2	5.200	0.000	0.003	-0.003	5.203
Left	9 to 10	5.2	5.2	5.2	5.200	0.000	0.037	0.037	5.163
Left	8 to 9	5.2	5.1	5.2	5.167	0.058	0.013	-0.013	5.180
Left	7 to 8	5	5	5	5.000	0.000	0.150	-0.150	5.150
Left	6 to 7	5.1	5	5	5.033	0.058	0.027	-0.027	5.060
Left	5 to 6	5.2	5.2	5.3	5.233	0.058	0.010	0.010	5.223
Middle	4 to 5	5.1	5.1	5.1	5.100	0.000	0.073	-0.073	5.173
Middle	3 to 4	5	4.9	4.9	4.933	0.058	0.013	-0.013	4.947
Middle	2 to 3	5.5	5.5	5.6	5.533	0.058	0.103	-0.103	5.637
Middle	1 to 2	4.9	4.9	4.9	4.900	0.000	0.047	0.047	4.853
Middle	0 to 1	4.4	4.4	4.4	4.400	0.000	0.130	-0.130	4.530
Middle	0 to -1	5.9	6	5.9	5.933	0.058	0.067	-0.067	6.000
Middle	-1 to -2	5.3	5.3	5	5.200	0.173	0.150	-0.150	5.350
Middle	-2 to -3	5.1	5.1	5.2	5.133	0.058	0.020	0.020	5.113
Middle	-3 to -4	5.2	5.1	5.1	5.133	0.058	0.033	0.033	5.100
Middle	-4 to -5	5.1	5.2	5.1	5.133	0.058	0.027	0.027	5.107
Right	-5 to -6	5	5.1	5.1	5.067	0.058	0.010	-0.010	5.077
Right	-6 to -7	5.2	5.2	5.1	5.167	0.058	0.020	-0.020	5.187
Right	-7 to -8	5.2	5.3	5.1	5.200	0.100	0.030	-0.030	5.230
Right	-8 to -9	5.1	5.1	5.2	5.133	0.058	0.017	0.017	5.117
Right	-9 to -10	5.2	5.2	5.1	5.167	0.058	0.010	-0.010	5.177
Right	-10 to -11	5	5	5.1	5.033	0.058	0.067	-0.067	5.100
Right	-11 to -12	5.2	5.2	5.2	5.200	0.000	0.047	-0.047	5.247
Right	-12 to -13	5.1	5.1	5.2	5.133	0.058	0.140	-0.140	5.273
Right	-13 to -14	5.1	5.2	5.1	5.133	0.058	0.050	-0.050	5.183
					Overall Avg		0.050	-0.024	
					Left Avg		0.028		
					Middle Avg		0.050		
					Right Avg		0.043		
					Overall SD		0.045	0.063	
					Left SD		0.046		
					Middle SD		0.048		
					Right SD		0.041		

TABLE 15.--Measurement Accuracy of a 13 cm, 10 sec, 0.4 mm Voxel Scan for Depth

Third	Points	T1	T2	T3	CB Mean	SD	Abs Diff	CBCT-DIR	DIR Mean
Front	14 to 15	5.1	5.2	5.2	5.167	0.058	0.083	-0.083	5.250
Front	13 to 14	5.2	5.1	5	5.100	0.100	0.023	-0.023	5.123
Front	12 to 13	5.2	5.1	5.1	5.133	0.058	0.003	-0.003	5.137
Front	11 to 12	5	4.9	5	4.967	0.058	0.223	-0.223	5.190
Front	10 to 11	5.2	5.1	5.2	5.167	0.058	0.093	-0.093	5.260
Front	9 to 10	5.1	5.1	5	5.067	0.058	0.083	-0.083	5.150
Front	8 to 9	5	5	5	5.000	0.000	0.067	-0.067	5.067
Front	7 to 8	5.1	5.1	5.2	5.133	0.058	0.050	-0.050	5.183
Front	6 to 7	5.2	5.3	5.3	5.267	0.058	0.000	0.000	5.267
Front	5 to 6	5	5.1	5	5.033	0.058	0.000	0.000	5.033
Middle	4 to 5	5	4.9	5	4.967	0.058	0.070	-0.070	5.037
Middle	3 to 4	5.3	5.2	5.2	5.233	0.058	0.060	-0.060	5.293
Middle	2 to 3	5	5	5.1	5.033	0.058	0.013	-0.013	5.047
Middle	1 to 2	5.2	5.1	5.2	5.167	0.058	0.007	0.007	5.160
Middle	0 to 1	5.1	5.2	5.2	5.167	0.058	0.153	0.153	5.013
Middle	0 to -1	4.9	4.9	4.9	4.900	0.000	0.207	-0.207	5.107
Middle	-1 to -2	5.2	5.4	5.4	5.333	0.115	0.100	0.100	5.233
Middle	-2 to -3	5	5.1	5.1	5.067	0.058	0.017	0.017	5.050
Middle	-3 to -4	5.2	5.2	5.2	5.200	0.000	0.030	-0.030	5.230
Middle	-4 to -5	5.1	5	5	5.033	0.058	0.077	-0.077	5.110
Back	-5 to -6	5.3	5.1	5.2	5.200	0.100	0.057	0.057	5.143
Back	-6 to -7	5.1	5.1	5.1	5.100	0.000	0.083	-0.083	5.183
Back	-7 to -8	5	5	5.2	5.067	0.115	0.090	-0.090	5.157
Back	-8 to -9	5.1	5	5.1	5.067	0.058	0.070	-0.070	5.137
Back	-9 to -10	5.3	5.2	5.3	5.267	0.058	0.003	0.003	5.263
Back	-10 to -11	5	5	5.1	5.033	0.058	0.050	-0.050	5.083
Back	-11 to -12	5.1	5.2	5.2	5.167	0.058	0.103	-0.103	5.270
Back	-12 to -13	5.1	5.2	5.1	5.133	0.058	0.050	0.050	5.083
Back	-13 to -14	5.2	5.2	5.2	5.200	0.000	0.010	0.010	5.190
Back	-14 to -15	5	5.1	5.1	5.067	0.058	0.063	-0.063	5.130
Back	-15 to -16	5.3	5.4	5.3	5.333	0.058	0.037	0.037	5.297
					Overall Avg		0.064	-0.036	
					Front Avg		0.042		
					Middle Avg		0.073		
					Back Avg		0.047		
					Overall SD		0.055	0.077	
					Front SD		0.067		
					Middle SD		0.065		
					Back SD		0.031		

TABLE 16.--Measurement Accuracy of a 13 cm, 20 sec, 0.3 mm Voxel Scan for Height

Third	Points	T1	T2	T3	CB Mean	SD	Abs Diff	CBCT-DIR	DIR Mean
Top	10 to 11	5.04	5.09	5.14	5.090	0.050	0.033	-0.033	5.123
Top	9 to 10	5.04	5.04	5.09	5.057	0.029	0.053	-0.053	5.110
Top	8 to 9	5.14	5	5.04	5.060	0.072	0.097	-0.097	5.157
Top	7 to 8	5.14	5.09	5.04	5.090	0.050	0.033	-0.033	5.123
Top	6 to 7	5.13	5.09	5.09	5.103	0.023	0.063	-0.063	5.167
Top	5 to 6	5.13	5.09	5.14	5.120	0.026	0.047	-0.047	5.167
Top	4 to 5	5.04	5.04	5.04	5.040	0.000	0.023	-0.023	5.063
Middle	3 to 4	5.18	5.14	5.18	5.167	0.023	0.050	-0.050	5.217
Middle	2 to 3	5	4.95	5.04	4.997	0.045	0.110	-0.110	5.107
Middle	1 to 2	5.04	5.19	5.05	5.093	0.084	0.110	-0.110	5.203
Middle	0 to 1	5.18	5.19	5.19	5.187	0.006	0.200	0.200	4.987
Middle	0 to -1	5	4.9	5	4.967	0.058	0.203	-0.203	5.170
Middle	-1 to -2	5.18	5.28	5.14	5.200	0.072	0.053	0.053	5.147
Middle	-2 to -3	5	5	5	5.000	0.000	0.053	-0.053	5.053
Middle	-3 to -4	5.23	5.19	5.24	5.220	0.026	0.003	-0.003	5.223
Bottom	-4 to -5	5.18	5.18	5.14	5.167	0.023	0.017	0.017	5.150
Bottom	-5 to -6	5.04	5.04	5	5.027	0.023	0.037	-0.037	5.063
Bottom	-6 to -7	5.13	5	5.09	5.073	0.067	0.127	-0.127	5.200
Bottom	-7 to -8	5.04	5.05	5	5.030	0.026	0.117	-0.117	5.147
Bottom	-8 to -9	5.13	5.09	5.14	5.120	0.026	0.043	-0.043	5.163
Bottom	-9 to -10	5.09	5.14	5.09	5.107	0.029	0.033	0.033	5.073
Bottom	-10 to -11	5.18	5.14	5.19	5.170	0.026	0.043	-0.043	5.213
Bottom	-11 to -12	5.09	5.14	5.05	5.093	0.045	0.030	0.030	5.063
Bottom	-12 to -13	5.23	5.28	5.23	5.247	0.029	0.017	-0.017	5.263
					Overall Avg		0.067	-0.039	
					Top Avg		0.028		
					Middle Avg		0.027		
					Bottom Avg		0.017		
					Overall SD		0.054	0.077	
					Top SD		0.025		
					Middle SD		0.073		
					Bottom SD		0.041		

TABLE 17.--Measurement Accuracy of a 13 cm, 20 sec, 0.3 mm Voxel Scan for Width

Third	Points	T1	T2	T3	CB Mean	SD	Abs Diff	CBCT-DIR	DIR Mean
Left	15 to 16	5.1	5.15	5.15	5.133	0.029	0.047	0.047	5.087
Left	14 to 15	5.09	5.15	5.15	5.130	0.035	0.067	-0.067	5.197
Left	13 to 14	5.19	5.09	5.15	5.143	0.050	0.023	0.023	5.120
Left	12 to 13	5.11	5.16	5.28	5.183	0.087	0.030	-0.030	5.213
Left	11 to 12	5.19	5.15	5.09	5.143	0.050	0.013	0.013	5.130
Left	10 to 11	5.29	5.21	5.27	5.257	0.042	0.053	0.053	5.203
Left	9 to 10	5.2	5.15	5.21	5.187	0.032	0.023	0.023	5.163
Left	8 to 9	5.19	5.09	5.04	5.107	0.076	0.073	-0.073	5.180
Left	7 to 8	5.19	5.09	5.09	5.123	0.058	0.027	-0.027	5.150
Left	6 to 7	5.1	5.04	5.15	5.097	0.055	0.037	0.037	5.060
Left	5 to 6	5.21	5.21	5.15	5.190	0.035	0.033	-0.033	5.223
Middle	4 to 5	5.29	5.15	5.09	5.177	0.103	0.003	0.003	5.173
Middle	3 to 4	4.99	4.98	4.86	4.943	0.072	0.003	-0.003	4.947
Middle	2 to 3	5.7	5.61	5.49	5.600	0.105	0.037	-0.037	5.637
Middle	1 to 2	4.99	4.92	4.98	4.963	0.038	0.110	0.110	4.853
Middle	0 to 1	4.39	4.41	4.41	4.403	0.012	0.127	-0.127	4.530
Middle	0 to -1	6.07	6.01	5.96	6.013	0.055	0.013	0.013	6.000
Middle	-1 to -2	5.2	5.26	5.32	5.260	0.060	0.090	-0.090	5.350
Middle	-2 to -3	5.15	5.15	5.09	5.130	0.035	0.017	0.017	5.113
Middle	-3 to -4	5.09	5.15	5.27	5.170	0.092	0.070	0.070	5.100
Middle	-4 to -5	5.15	5.04	5.04	5.077	0.064	0.030	-0.030	5.107
Right	-5 to -6	5.04	5.03	5.03	5.033	0.006	0.043	-0.043	5.077
Right	-6 to -7	5.21	5.15	5.15	5.170	0.035	0.017	-0.017	5.187
Right	-7 to -8	5.21	5.32	5.21	5.247	0.064	0.017	0.017	5.230
Right	-8 to -9	5.15	5.21	5.27	5.210	0.060	0.093	0.093	5.117
Right	-9 to -10	5.22	5.16	5.16	5.180	0.035	0.003	0.003	5.177
Right	-10 to -11	5.03	5.09	4.97	5.030	0.060	0.070	-0.070	5.100
Right	-11 to -12	5.1	5.16	5.22	5.160	0.060	0.087	-0.087	5.247
Right	-12 to -13	5.21	5.15	5.15	5.170	0.035	0.103	-0.103	5.273
Right	-13 to -14	5.21	5.15	5.15	5.170	0.035	0.013	-0.013	5.183
					Overall Avg		0.046	-0.011	
					Left Avg		0.040		
					Middle Avg		0.017		
					Right Avg		0.050		
					Overall SD		0.035	0.057	
					Left SD		0.019		
					Middle SD		0.046		
					Right SD		0.039		

TABLE 18.--Measurement Accuracy of a 13 cm, 20 sec, 0.3 mm Voxel Scan for Depth

Third	Points	T1	T2	T3	CB Mean	SD	Abs Diff	CBCT-DIR	DIR Mean
Front	14 to 15	5.15	5.15	5.15	5.150	0.000	0.100	-0.100	5.250
Front	13 to 14	4.98	5.09	4.98	5.017	0.064	0.107	-0.107	5.123
Front	12 to 13	5.03	5.03	5.03	5.030	0.000	0.107	-0.107	5.137
Front	11 to 12	4.98	5.09	5.15	5.073	0.086	0.117	-0.117	5.190
Front	10 to 11	5.15	5.09	5.2	5.147	0.055	0.113	-0.113	5.260
Front	9 to 10	5.16	5.11	5.16	5.143	0.029	0.007	-0.007	5.150
Front	8 to 9	4.97	4.98	5.03	4.993	0.032	0.073	-0.073	5.067
Front	7 to 8	5.09	5.21	5.09	5.130	0.069	0.053	-0.053	5.183
Front	6 to 7	5.26	5.15	5.21	5.207	0.055	0.060	-0.060	5.267
Front	5 to 6	5.03	5.03	5.03	5.030	0.000	0.003	-0.003	5.033
Middle	4 to 5	5.03	4.97	5.03	5.010	0.035	0.027	-0.027	5.037
Middle	3 to 4	5.26	5.21	5.32	5.263	0.055	0.030	-0.030	5.293
Middle	2 to 3	4.92	4.97	5.04	4.977	0.060	0.070	-0.070	5.047
Middle	1 to 2	5.15	5.2	5.21	5.187	0.032	0.027	0.027	5.160
Middle	0 to 1	5.11	5.1	5.1	5.103	0.006	0.090	0.090	5.013
Middle	0 to -1	4.86	4.8	4.97	4.877	0.086	0.230	-0.230	5.107
Middle	-1 to -2	5.38	5.32	5.38	5.360	0.035	0.127	0.127	5.233
Middle	-2 to -3	5.09	4.97	5.09	5.050	0.069	0.000	0.000	5.050
Middle	-3 to -4	5.21	5.21	5.15	5.190	0.035	0.040	-0.040	5.230
Middle	-4 to -5	5.09	5.2	5.03	5.107	0.086	0.003	-0.003	5.110
Back	-5 to -6	5.22	5.1	5.22	5.180	0.069	0.037	0.037	5.143
Back	-6 to -7	5.09	5.15	5.15	5.130	0.035	0.053	-0.053	5.183
Back	-7 to -8	5.15	5.03	5.03	5.070	0.069	0.087	-0.087	5.157
Back	-8 to -9	5.1	5.16	5.22	5.160	0.060	0.023	0.023	5.137
Back	-9 to -10	5.21	5.15	5.21	5.190	0.035	0.073	-0.073	5.263
Back	-10 to -11	5.03	5.03	5.09	5.050	0.035	0.033	-0.033	5.083
Back	-11 to -12	5.2	5.21	5.26	5.223	0.032	0.047	-0.047	5.270
Back	-12 to -13	5.03	5.03	5.03	5.030	0.000	0.053	-0.053	5.083
Back	-13 to -14	5.15	5.09	5.04	5.093	0.055	0.097	-0.097	5.190
Back	-14 to -15	5.09	5.03	5.15	5.090	0.060	0.040	-0.040	5.130
Back	-15 to -16	5.21	5.26	5.32	5.263	0.055	0.033	-0.033	5.297
					Overall Avg		0.063	-0.044	
					Front Avg		0.052		
					Middle Avg		0.015		
					Back Avg		0.035		
					Overall SD		0.048	0.067	
					Front SD		0.043		
					Middle SD		0.070		
					Back SD		0.024		

TABLE 19.--Measurement Accuracy of a 13 cm, 40 sec, 0.25 mm Voxel Scan for Height

Third	Points	T1	T2	T3	CB Mean	SD	Abs Diff	CBCT-DIR	DIR Mean
Top	10 to 11	5.14	5.1	5.16	5.133	0.031	0.010	0.010	5.123
Top	9 to 10	5.01	5.03	5.03	5.023	0.012	0.087	-0.087	5.110
Top	8 to 9	5.01	5.07	5.11	5.063	0.050	0.093	-0.093	5.157
Top	7 to 8	5.05	5.1	5.07	5.073	0.025	0.050	-0.050	5.123
Top	6 to 7	5.22	5.1	5.2	5.173	0.064	0.007	0.007	5.167
Top	5 to 6	5.09	5.13	5.03	5.083	0.050	0.083	-0.083	5.167
Top	4 to 5	5.01	5.03	4.99	5.010	0.020	0.053	-0.053	5.063
Middle	3 to 4	5.22	5.2	5.15	5.190	0.036	0.027	-0.027	5.217
Middle	2 to 3	5.01	5.03	5.03	5.023	0.012	0.083	-0.083	5.107
Middle	1 to 2	5.14	5.1	5.16	5.133	0.031	0.070	-0.070	5.203
Middle	0 to 1	5.14	5.17	5.2	5.170	0.030	0.183	0.183	4.987
Middle	0 to -1	4.97	4.87	4.99	4.943	0.064	0.227	-0.227	5.170
Middle	-1 to -2	5.13	5.28	5.19	5.200	0.075	0.053	0.053	5.147
Middle	-2 to -3	4.94	5.04	5.12	5.033	0.090	0.020	-0.020	5.053
Middle	-3 to -4	5.2	5.24	5.24	5.227	0.023	0.003	0.003	5.223
Bottom	-4 to -5	5.27	5.11	5.19	5.190	0.080	0.040	0.040	5.150
Bottom	-5 to -6	5	5.15	5.07	5.073	0.075	0.010	0.010	5.063
Bottom	-6 to -7	5.01	4.99	5.03	5.010	0.020	0.190	-0.190	5.200
Bottom	-7 to -8	4.94	5.08	5.24	5.087	0.150	0.060	-0.060	5.147
Bottom	-8 to -9	5.07	5.12	5.15	5.113	0.040	0.050	-0.050	5.163
Bottom	-9 to -10	5.1	5.07	5.07	5.080	0.017	0.007	0.007	5.073
Bottom	-10 to -11	5.17	5.24	5.15	5.187	0.047	0.027	-0.027	5.213
Bottom	-11 to -12	5.04	5.04	5.12	5.067	0.046	0.003	0.003	5.063
Bottom	-12 to -13	5.3	5.24	5.24	5.260	0.035	0.003	-0.003	5.263
					Overall Avg		0.060	-0.034	
					Top Avg		0.032		
					Middle Avg		0.015		
					Bottom Avg		0.022		
					Overall SD		0.062	0.080	
					Top SD		0.036		
					Middle SD		0.080		
					Bottom SD		0.059		

TABLE 20.--Measurement Accuracy of a 13 cm, 40 sec, 0.25 mm Voxel Scan for Width

Third	Points	T1	T2	T3	CB Mean	SD	Abs Diff	CBCT-DIR	DIR Mean
Left	15 to 16	5.09	5.16	5.11	5.120	0.036	0.033	0.033	5.087
Left	14 to 15	5.31	5.39	5.24	5.313	0.075	0.117	0.117	5.197
Left	13 to 14	5.15	5.08	5.09	5.107	0.038	0.013	-0.013	5.120
Left	12 to 13	5.2	5.2	5.2	5.200	0.000	0.013	-0.013	5.213
Left	11 to 12	5.15	5.14	5.08	5.123	0.038	0.007	-0.007	5.130
Left	10 to 11	5.08	5.17	5.24	5.163	0.080	0.040	-0.040	5.203
Left	9 to 10	5.22	5.23	5.16	5.203	0.038	0.040	0.040	5.163
Left	8 to 9	5.25	5.27	5.25	5.257	0.012	0.077	0.077	5.180
Left	7 to 8	5.22	5.14	5.21	5.190	0.044	0.040	0.040	5.150
Left	6 to 7	5.11	5.04	5.2	5.117	0.080	0.057	0.057	5.060
Left	5 to 6	5.3	5.25	5.3	5.283	0.029	0.060	0.060	5.223
Middle	4 to 5	5.14	5.08	5.23	5.150	0.075	0.023	-0.023	5.173
Middle	3 to 4	4.89	5.02	5.01	4.973	0.072	0.027	0.027	4.947
Middle	2 to 3	5.73	5.65	5.66	5.680	0.044	0.043	0.043	5.637
Middle	1 to 2	4.8	4.88	4.82	4.833	0.042	0.020	-0.020	4.853
Middle	0 to 1	4.47	4.46	4.44	4.457	0.015	0.073	-0.073	4.530
Middle	0 to -1	5.94	6.01	6	5.983	0.038	0.017	-0.017	6.000
Middle	-1 to -2	5.23	5.24	5.37	5.280	0.078	0.070	-0.070	5.350
Middle	-2 to -3	5.09	5.08	5.02	5.063	0.038	0.050	-0.050	5.113
Middle	-3 to -4	5.24	5.16	5.25	5.217	0.049	0.117	0.117	5.100
Middle	-4 to -5	5.24	5.16	5.25	5.217	0.049	0.110	0.110	5.107
Right	-5 to -6	5.08	5.03	5.1	5.070	0.036	0.007	-0.007	5.077
Right	-6 to -7	5.24	5.16	5.17	5.190	0.044	0.003	0.003	5.187
Right	-7 to -8	5.38	5.23	5.22	5.277	0.090	0.047	0.047	5.230
Right	-8 to -9	5.23	5.08	5.08	5.130	0.087	0.013	0.013	5.117
Right	-9 to -10	5.27	5.25	5.13	5.217	0.076	0.040	0.040	5.177
Right	-10 to -11	5.08	5.01	5	5.030	0.044	0.070	-0.070	5.100
Right	-11 to -12	5.18	5.12	5.11	5.137	0.038	0.110	-0.110	5.247
Right	-12 to -13	5.17	5.17	5.11	5.150	0.035	0.123	-0.123	5.273
Right	-13 to -14	5.08	5.29	5.22	5.197	0.107	0.013	0.013	5.183
					Overall Avg		0.049	0.007	
					Left Avg		0.047		
					Middle Avg		0.067		
					Right Avg		0.047		
					Overall SD		0.037	0.062	
					Left SD		0.032		
					Middle SD		0.037		
					Right SD		0.045		

TABLE 21.--Measurement Accuracy of a 13 cm, 40 sec, 0.25 mm Voxel Scan for Depth

Third	Points	T1	T2	T3	CB Mean	SD	Abs Diff	CBCT-DIR	DIR Mean
Front	14 to 15	5.17	5.17	5.11	5.150	0.035	0.100	-0.100	5.250
Front	13 to 14	4.93	5.03	5.04	5.000	0.061	0.123	-0.123	5.123
Front	12 to 13	5.08	5.16	5.04	5.093	0.061	0.043	-0.043	5.137
Front	11 to 12	5.17	5.03	4.98	5.060	0.098	0.130	-0.130	5.190
Front	10 to 11	5.09	5.15	5.28	5.173	0.097	0.087	-0.087	5.260
Front	9 to 10	5.15	5.23	5.11	5.163	0.061	0.013	0.013	5.150
Front	8 to 9	5.08	4.98	5.09	5.050	0.061	0.017	-0.017	5.067
Front	7 to 8	5.23	5.1	5.1	5.143	0.075	0.040	-0.040	5.183
Front	6 to 7	5.16	5.11	5.22	5.163	0.055	0.103	-0.103	5.267
Front	5 to 6	5.08	5.1	5.04	5.073	0.031	0.040	0.040	5.033
Middle	4 to 5	5.01	5.05	5.03	5.030	0.020	0.007	-0.007	5.037
Middle	3 to 4	5.3	5.16	5.28	5.247	0.076	0.047	-0.047	5.293
Middle	2 to 3	5.02	5.16	5.05	5.077	0.074	0.030	0.030	5.047
Middle	1 to 2	5.08	4.97	5.09	5.047	0.067	0.113	-0.113	5.160
Middle	0 to 1	5.25	5.12	5.21	5.193	0.067	0.180	0.180	5.013
Middle	0 to -1	4.93	4.91	4.91	4.917	0.012	0.190	-0.190	5.107
Middle	-1 to -2	5.37	5.45	5.34	5.387	0.057	0.153	0.153	5.233
Middle	-2 to -3	5.08	5.04	5.09	5.070	0.026	0.020	0.020	5.050
Middle	-3 to -4	5.16	5.24	5.28	5.227	0.061	0.003	-0.003	5.230
Middle	-4 to -5	5.16	5.22	5.1	5.160	0.060	0.050	0.050	5.110
Back	-5 to -6	5.12	5.11	5.06	5.097	0.032	0.047	-0.047	5.143
Back	-6 to -7	5.16	5.23	5.09	5.160	0.070	0.023	-0.023	5.183
Back	-7 to -8	5.08	5.09	5.16	5.110	0.044	0.047	-0.047	5.157
Back	-8 to -9	5.18	5.13	5.11	5.140	0.036	0.003	0.003	5.137
Back	-9 to -10	5.17	5.23	5.28	5.227	0.055	0.037	-0.037	5.263
Back	-10 to -11	5.02	5.04	4.98	5.013	0.031	0.070	-0.070	5.083
Back	-11 to -12	5.1	5.23	5.16	5.163	0.065	0.107	-0.107	5.270
Back	-12 to -13	4.87	4.97	4.98	4.940	0.061	0.143	-0.143	5.083
Back	-13 to -14	5.08	5.04	5.1	5.073	0.031	0.117	-0.117	5.190
Back	-14 to -15	5.01	5.11	5.04	5.053	0.051	0.077	-0.077	5.130
Back	-15 to -16	5.15	5.09	5.28	5.173	0.097	0.123	-0.123	5.297
					Overall Avg		0.074	-0.042	
					Front Avg		0.070		
					Middle Avg		0.028		
					Back Avg		0.085		
					Overall SD		0.054	0.082	
					Front SD		0.044		
					Middle SD		0.073		
					Back SD		0.045		

TABLE 22.--Measurement Accuracy of an 8 cm, 20 sec, 0.4 mm Voxel Scan for Height

Third	Points	T1	T2	T3	CB Mean	SD	Abs Diff	CBCT-DIR	DIR Mean
Top	6 to 7	5.2	5.2	5.3	5.233	0.058	0.067	0.067	5.167
Top	5 to 6	5.1	5.1	5.1	5.100	0.000	0.067	-0.067	5.167
Top	4 to 5	5.1	5.0	5.0	5.033	0.058	0.030	-0.030	5.063
Top	3 to 4	5.1	5.1	5.1	5.100	0.000	0.117	-0.117	5.217
Middle	2 to 3	5.0	5.0	5.0	5.000	0.000	0.107	-0.107	5.107
Middle	1 to 2	5.2	5.2	5.1	5.167	0.058	0.037	-0.037	5.203
Middle	0 to 1	5.2	5.2	5.1	5.167	0.058	0.180	0.180	4.987
Middle	0 to -1	5.0	4.9	4.9	4.933	0.058	0.237	-0.237	5.170
Middle	-1 to -2	5.3	5.3	5.2	5.267	0.058	0.120	0.120	5.147
Middle	-2 to -3	5.1	5.0	5.1	5.067	0.058	0.013	0.013	5.053
Bottom	-3 to -4	5.2	5.2	5.2	5.200	0.000	0.023	-0.023	5.223
Bottom	-4 to -5	5.2	5.1	5.2	5.167	0.058	0.017	0.017	5.150
Bottom	-5 to -6	5.1	5.1	5.2	5.133	0.058	0.070	0.070	5.063
Bottom	-6 to -7	5.1	5.1	5.2	5.133	0.058	0.067	-0.067	5.200
Bottom	-7 to -8	5.0	5.1	5.1	5.067	0.058	0.080	-0.080	5.147
					Overall Avg		0.082	-0.020	
					Top Avg		0.092		
					Middle Avg		0.060		
					Bottom Avg		0.052		
					Overall SD		0.063	0.103	
					Top SD		0.036		
					Middle SD		0.084		
					Bottom SD		0.029		

TABLE 23.--Measurement Accuracy of an 8 cm, 20 sec, 0.4 mm Voxel Scan for Width

Third	Points	T1	T2	T3	CB Mean	SD	Abs Diff	CBCT-DIR	DIR Mean
Left	15 to 16	5.2	5.1	5.2	5.167	0.058	0.080	0.080	5.087
Left	14 to 15	5.1	5.1	5.2	5.133	0.058	0.063	-0.063	5.197
Left	13 to 14	5.2	5.0	5.1	5.100	0.100	0.020	-0.020	5.120
Left	12 to 13	5.2	5.2	5.3	5.233	0.058	0.020	0.020	5.213
Left	11 to 12	5.0	5.2	5.1	5.100	0.100	0.030	-0.030	5.130
Left	10 to 11	5.1	5.2	5.2	5.167	0.058	0.037	-0.037	5.203
Left	9 to 10	5.2	5.1	5.0	5.100	0.100	0.063	-0.063	5.163
Left	8 to 9	5.2	5.2	5.2	5.200	0.000	0.020	0.020	5.180
Left	7 to 8	5.1	5.2	5.1	5.133	0.058	0.017	-0.017	5.150
Left	6 to 7	5.2	5.1	5.2	5.167	0.058	0.107	0.107	5.060
Left	5 to 6	5.2	5.2	5.3	5.233	0.058	0.010	0.010	5.223
Middle	4 to 5	5.1	5.2	5.2	5.167	0.058	0.007	-0.007	5.173
Middle	3 to 4	5.0	4.9	5.0	4.967	0.058	0.020	0.020	4.947
Middle	2 to 3	5.5	5.7	5.6	5.600	0.100	0.037	-0.037	5.637
Middle	1 to 2	4.8	4.9	4.8	4.833	0.058	0.020	-0.020	4.853
Middle	0 to 1	4.5	4.7	4.6	4.600	0.100	0.070	0.070	4.530
Middle	0 to -1	5.8	5.9	5.9	5.867	0.058	0.133	-0.133	6.000
Middle	-1 to -2	5.4	5.4	5.3	5.367	0.058	0.017	0.017	5.350
Middle	-2 to -3	5.0	5.1	5.1	5.067	0.058	0.047	-0.047	5.113
Middle	-3 to -4	5.3	5.2	5.2	5.233	0.058	0.133	0.133	5.100
Middle	-4 to -5	5.2	5.1	5.2	5.167	0.058	0.060	0.060	5.107
Right	-5 to -6	5.2	5.1	5.1	5.133	0.058	0.057	0.057	5.077
Right	-6 to -7	5.2	5.1	5.2	5.167	0.058	0.020	-0.020	5.187
Right	-7 to -8	5.2	5.2	5.3	5.233	0.058	0.003	0.003	5.230
Right	-8 to -9	5.1	5.1	5.1	5.100	0.000	0.017	-0.017	5.117
Right	-9 to -10	5.2	5.2	5.2	5.200	0.000	0.023	0.023	5.177
Right	-10 to -11	5.1	5.0	5.0	5.033	0.058	0.067	-0.067	5.100
Right	-11 to -12	5.3	5.2	5.0	5.167	0.153	0.080	-0.080	5.247
Right	-12 to -13	5.2	5.2	5.2	5.200	0.000	0.073	-0.073	5.273
Right	-13 to -14	5.2	5.1	5.2	5.167	0.058	0.017	-0.017	5.183
					Overall Avg		0.046	-0.004	
					Left Avg		0.045		
					Middle Avg		0.033		
					Right Avg		0.040		
					Overall SD		0.036	0.058	
					Left SD		0.031		
					Middle SD		0.046		
					Right SD		0.029		

TABLE 24.--Measurement Accuracy of an 8 cm, 20 sec, 0.4 mm Voxel Scan for Depth

Third	Points	T1	T2	T3	CB Mean	SD	Abs Diff	CBCT-DIR	DIR Mean
Front	14 to 15	5.1	5.1	5.0	5.067	0.058	0.183	-0.183	5.250
Front	13 to 14	4.9	5.0	4.9	4.933	0.058	0.190	-0.190	5.123
Front	12 to 13	5.2	5.1	5.1	5.133	0.058	0.003	-0.003	5.137
Front	11 to 12	5.2	5.1	5.1	5.133	0.058	0.057	-0.057	5.190
Front	10 to 11	5.2	5.1	5.3	5.200	0.100	0.060	-0.060	5.260
Front	9 to 10	5.1	5.1	5.1	5.100	0.000	0.050	-0.050	5.150
Front	8 to 9	5.0	4.9	4.9	4.933	0.058	0.133	-0.133	5.067
Front	7 to 8	5.1	5.1	5.2	5.133	0.058	0.050	-0.050	5.183
Front	6 to 7	5.2	5.2	5.1	5.167	0.058	0.100	-0.100	5.267
Front	5 to 6	5.0	5.0	5.0	5.000	0.000	0.033	-0.033	5.033
Middle	4 to 5	5.0	5.0	5.0	5.000	0.000	0.037	-0.037	5.037
Middle	3 to 4	5.3	5.2	5.4	5.300	0.100	0.007	0.007	5.293
Middle	2 to 3	4.9	4.9	5.0	4.933	0.058	0.113	-0.113	5.047
Middle	1 to 2	5.1	5.1	5.2	5.133	0.058	0.027	-0.027	5.160
Middle	0 to 1	5.1	5.1	5.0	5.067	0.058	0.053	0.053	5.013
Middle	0 to -1	5.0	5.1	5.0	5.033	0.058	0.073	-0.073	5.107
Middle	-1 to -2	5.3	5.5	5.5	5.433	0.115	0.200	0.200	5.233
Middle	-2 to -3	5.0	5.0	5.0	5.000	0.000	0.050	-0.050	5.050
Middle	-3 to -4	5.2	5.3	5.2	5.233	0.058	0.003	0.003	5.230
Middle	-4 to -5	5.1	5.2	5.2	5.167	0.058	0.057	0.057	5.110
Back	-5 to -6	5.2	5.2	5.2	5.200	0.000	0.057	0.057	5.143
Back	-6 to -7	5.1	5.1	5.2	5.133	0.058	0.050	-0.050	5.183
Back	-7 to -8	5.0	5.0	5.1	5.033	0.058	0.123	-0.123	5.157
Back	-8 to -9	5.2	5.1	5.2	5.167	0.058	0.030	0.030	5.137
Back	-9 to -10	5.3	5.2	5.2	5.233	0.058	0.030	-0.030	5.263
Back	-10 to -11	5.1	5.1	5.0	5.067	0.058	0.017	-0.017	5.083
Back	-11 to -12	5.2	5.3	5.4	5.300	0.100	0.030	0.030	5.270
Back	-12 to -13	5.1	5.0	5.1	5.067	0.058	0.017	-0.017	5.083
Back	-13 to -14	5.1	5.2	5.0	5.100	0.100	0.090	-0.090	5.190
Back	-14 to -15	4.9	5.0	5.2	5.033	0.153	0.097	-0.097	5.130
Back	-15 to -16	5.4	5.5	5.5	5.467	0.058	0.170	0.170	5.297
					Overall Avg		0.071	-0.032	
					Front Avg		0.108		
					Middle Avg		0.047		
					Back Avg		0.113		
					Overall SD		0.056	0.085	
					Front SD		0.064		
					Middle SD		0.058		
					Back SD		0.050		

TABLE 25.--Measurement Accuracy of a 6 cm, 20 sec, 0.4 mm Voxel Denex Mandibular Scan for Height

Third	Points	T1	T2	T3	CB Mean	SD	Abs Diff	CBCT-DIR	DIR Mean
Top	4 to 5	5.1	5.1	5.1	5.100	0.000	0.037	0.037	5.063
Top	3 to 4	5.2	5.2	5.2	5.200	0.000	0.017	-0.017	5.217
Top	2 to 3	4.9	4.8	5	4.900	0.100	0.207	-0.207	5.107
Middle	1 to 2	5.2	5.2	5.2	5.200	0.000	0.003	-0.003	5.203
Middle	0 to 1	5.2	5.2	5.2	5.200	0.000	0.213	0.213	4.987
Middle	0 to -1	4.9	5	5	4.967	0.058	0.203	-0.203	5.170
Middle	-1 to -2	5.1	5.2	5.2	5.167	0.058	0.020	0.020	5.147
Bottom	-2 to -3	5	4.9	5	4.967	0.058	0.087	-0.087	5.053
Bottom	-3 to -4	5.2	5.2	5.3	5.233	0.058	0.010	0.010	5.223
Bottom	-4 to -5	5.2	5.2	5.2	5.200	0.000	0.050	0.050	5.150
					Overall Avg		0.085	-0.019	
					Top Avg		0.122		
					Middle Avg		0.012		
					Bottom Avg		0.068		
					Overall SD		0.088	0.124	
					Top SD		0.104		
					Middle SD		0.114		
					Bottom SD		0.038		

TABLE 26.--Measurement Accuracy of a 6 cm, 20 sec, 0.4 mm Voxel Denex Mandibular Scan for Width

Third	Points	T1	T2	T3	CB Mean	SD	Abs Diff	CBCT-DIR	DIR Mean
Left	15 to 16	5.2	5.2	5.1	5.167	0.058	0.080	0.080	5.087
Left	14 to 15	5.2	5.1	5.2	5.167	0.058	0.030	-0.030	5.197
Left	13 to 14	5.2	5.2	5.1	5.167	0.058	0.047	0.047	5.120
Left	12 to 13	5.2	5.2	5.3	5.233	0.058	0.020	0.020	5.213
Left	11 to 12	5.1	5.2	5.1	5.133	0.058	0.003	0.003	5.130
Left	10 to 11	5.2	5.2	5.2	5.200	0.000	0.003	-0.003	5.203
Left	9 to 10	5.2	5.1	5.2	5.167	0.058	0.003	0.003	5.163
Left	8 to 9	5.2	5.2	5.1	5.167	0.058	0.013	-0.013	5.180
Left	7 to 8	5.1	5	5.1	5.067	0.058	0.083	-0.083	5.150
Left	6 to 7	5	5	5.1	5.033	0.058	0.027	-0.027	5.060
Left	5 to 6	5.2	5.1	5.2	5.167	0.058	0.057	-0.057	5.223
Middle	4 to 5	5.2	5.1	5.1	5.133	0.058	0.040	-0.040	5.173
Middle	3 to 4	5	4.9	5	4.967	0.058	0.020	0.020	4.947
Middle	2 to 3	5.6	5.6	5.5	5.567	0.058	0.070	-0.070	5.637
Middle	1 to 2	4.9	4.9	4.8	4.867	0.058	0.013	0.013	4.853
Middle	0 to 1	4.5	4.5	4.5	4.500	0.000	0.030	-0.030	4.530
Middle	0 to -1	5.9	5.9	5.8	5.867	0.058	0.133	-0.133	6.000
Middle	-1 to -2	5.3	5.4	5.4	5.367	0.058	0.017	0.017	5.350
Middle	-2 to -3	5.1	5	5	5.033	0.058	0.080	-0.080	5.113
Middle	-3 to -4	5.2	5.2	5.3	5.233	0.058	0.133	0.133	5.100
Middle	-4 to -5	5.1	5.1	5.1	5.100	0.000	0.007	-0.007	5.107
Right	-5 to -6	5	5	5	5.000	0.000	0.077	-0.077	5.077
Right	-6 to -7	5.2	5.1	5.2	5.167	0.058	0.020	-0.020	5.187
Right	-7 to -8	5.3	5.2	5.2	5.233	0.058	0.003	0.003	5.230
Right	-8 to -9	5.2	5.1	5.2	5.167	0.058	0.050	0.050	5.117
Right	-9 to -10	5.2	5.2	5.2	5.200	0.000	0.023	0.023	5.177
Right	-10 to -11	5	5	4.9	4.967	0.058	0.133	-0.133	5.100
Right	-11 to -12	5.1	5.2	5.2	5.167	0.058	0.080	-0.080	5.247
Right	-12 to -13	5.2	5.2	5.2	5.200	0.000	0.073	-0.073	5.273
Right	-13 to -14	5.1	5.1	5.2	5.133	0.058	0.050	-0.050	5.183
					Overall Avg		0.047	-0.020	
					Left Avg		0.068		
					Middle Avg		0.023		
					Right Avg		0.057		
					Overall SD		0.040	0.059	
					Left SD		0.030		
					Middle SD		0.048		
					Right SD		0.040		

TABLE 27.--Measurement Accuracy of a 6 cm, 20 sec, 0.4 mm Voxel Denex Mandibular Scan for Depth

Third	Points	T1	T2	T3	CB Mean	SD	Abs Diff	CBCT-DIR	DIR Mean
Front	14 to 15	5.1	5.2	5.1	5.133	0.058	0.117	-0.117	5.250
Front	13 to 14	5.1	5	5.1	5.067	0.058	0.057	-0.057	5.123
Front	12 to 13	5.1	5.2	5.1	5.133	0.058	0.003	-0.003	5.137
Front	11 to 12	5	5	5.2	5.067	0.115	0.123	-0.123	5.190
Front	10 to 11	5.1	5.2	5.2	5.167	0.058	0.093	-0.093	5.260
Front	9 to 10	5	5	5.1	5.033	0.058	0.117	-0.117	5.150
Front	8 to 9	5	5.1	5	5.033	0.058	0.033	-0.033	5.067
Front	7 to 8	5.2	5.2	5.1	5.167	0.058	0.017	-0.017	5.183
Front	6 to 7	5.2	5.2	5.2	5.200	0.000	0.067	-0.067	5.267
Front	5 to 6	5	5	5	5.000	0.000	0.033	-0.033	5.033
Middle	4 to 5	5	4.9	5	4.967	0.058	0.070	-0.070	5.037
Middle	3 to 4	5.3	5.3	5.3	5.300	0.000	0.007	0.007	5.293
Middle	2 to 3	4.9	4.9	4.9	4.900	0.000	0.147	-0.147	5.047
Middle	1 to 2	5.1	5.2	5.2	5.167	0.058	0.007	0.007	5.160
Middle	0 to 1	5.2	5.2	5.2	5.200	0.000	0.187	0.187	5.013
Middle	0 to -1	4.9	5	4.9	4.933	0.058	0.173	-0.173	5.107
Middle	-1 to -2	5.2	5.3	5.3	5.267	0.058	0.033	0.033	5.233
Middle	-2 to -3	5.1	5.1	5.1	5.100	0.000	0.050	0.050	5.050
Middle	-3 to -4	5.2	5.2	5.2	5.200	0.000	0.030	-0.030	5.230
Middle	-4 to -5	5.2	5.2	5.2	5.200	0.000	0.090	0.090	5.110
Back	-5 to -6	5.2	5.2	5.1	5.167	0.058	0.023	0.023	5.143
Back	-6 to -7	5.2	5.2	5.2	5.200	0.000	0.017	0.017	5.183
Back	-7 to -8	5.1	5.2	5.1	5.133	0.058	0.023	-0.023	5.157
Back	-8 to -9	5.2	5.2	5.2	5.200	0.000	0.063	0.063	5.137
Back	-9 to -10	5.2	5.2	5.2	5.200	0.000	0.063	-0.063	5.263
Back	-10 to -11	5	5.1	5.1	5.067	0.058	0.017	-0.017	5.083
Back	-11 to -12	5.3	5.3	5.2	5.267	0.058	0.003	-0.003	5.270
Back	-12 to -13	5.1	5.1	5	5.067	0.058	0.017	-0.017	5.083
Back	-13 to -14	5	5.1	5.2	5.100	0.100	0.090	-0.090	5.190
Back	-14 to -15	5.1	5.2	5.1	5.133	0.058	0.003	0.003	5.130
Back	-15 to -16	5.2	5.2	5.2	5.200	0.000	0.097	-0.097	5.297
					Overall Avg		0.060	-0.029	
					Front Avg		0.075		
					Middle Avg		0.080		
					Back Avg		0.060		
					Overall SD		0.052	0.074	
					Front SD		0.044		
					Middle SD		0.068		
					Back SD		0.034		

TABLE 28.--Measurement Accuracy of a 6 cm, 20 sec, 0.4 mm Voxel Denex Maxillary Scan for Height

Third	Points	T1	T2	T3	CB Mean	SD	Abs Diff	CBCT-DIR	DIR Mean
Top	4 to 5	5	5.1	5.1	5.067	0.058	0.003	0.003	5.063
Top	3 to 4	5.1	5.2	5.2	5.167	0.058	0.050	-0.050	5.217
Top	2 to 3	4.9	4.9	5	4.933	0.058	0.173	-0.173	5.107
Middle	1 to 2	5.1	5.2	5.2	5.167	0.058	0.037	-0.037	5.203
Middle	0 to 1	5.1	5.2	5.1	5.133	0.058	0.147	0.147	4.987
Middle	0 to -1	5	5	5	5.000	0.000	0.170	-0.170	5.170
Middle	-1 to -2	5.1	5.2	5.2	5.167	0.058	0.020	0.020	5.147
Bottom	-2 to -3	5	5	5	5.000	0.000	0.053	-0.053	5.053
Bottom	-3 to -4	5.3	5.2	5.2	5.233	0.058	0.010	0.010	5.223
Bottom	-4 to -5	5.2	5.2	5.2	5.200	0.000	0.050	0.050	5.150
					Overall Avg		0.071	-0.025	
					Top Avg		0.088		
					Middle Avg		0.028		
					Bottom Avg		0.052		
					Overall SD		0.066	0.096	
					Top SD		0.088		
					Middle SD		0.076		
					Bottom SD		0.024		

TABLE 29.--Measurement Accuracy of a 6 cm, 20 sec, 0.4 mm Voxel Denex Maxillary Scan for Width

Third	Points	T1	T2	T3	CB Mean	SD	Abs Diff	CBCT-DIR	DIR Mean
Left	15 to 16	5	5.1	5.1	5.067	0.058	0.020	-0.020	5.087
Left	14 to 15	5.2	5.2	5.1	5.167	0.058	0.030	-0.030	5.197
Left	13 to 14	5.1	5.1	5.1	5.100	0.000	0.020	-0.020	5.120
Left	12 to 13	5.1	5.2	5.3	5.200	0.100	0.013	-0.013	5.213
Left	11 to 12	5.1	5.1	5.1	5.100	0.000	0.030	-0.030	5.130
Left	10 to 11	5.2	5.2	5.2	5.200	0.000	0.003	-0.003	5.203
Left	9 to 10	5.1	5.2	5.1	5.133	0.058	0.030	-0.030	5.163
Left	8 to 9	5.1	5.2	5.2	5.167	0.058	0.013	-0.013	5.180
Left	7 to 8	5	5.1	5	5.033	0.058	0.117	-0.117	5.150
Left	6 to 7	5.1	5.1	5.1	5.100	0.000	0.040	0.040	5.060
Left	5 to 6	5.2	5.2	5.2	5.200	0.000	0.023	-0.023	5.223
Middle	4 to 5	5.1	5.1	5.1	5.100	0.000	0.073	-0.073	5.173
Middle	3 to 4	5	5	5.1	5.033	0.058	0.087	0.087	4.947
Middle	2 to 3	5.6	5.6	5.6	5.600	0.000	0.037	-0.037	5.637
Middle	1 to 2	4.9	4.8	4.9	4.867	0.058	0.013	0.013	4.853
Middle	0 to 1	4.5	4.4	4.4	4.433	0.058	0.097	-0.097	4.530
Middle	0 to -1	5.9	5.9	5.9	5.900	0.000	0.100	-0.100	6.000
Middle	-1 to -2	5.3	5.3	5.3	5.300	0.000	0.050	-0.050	5.350
Middle	-2 to -3	5.1	5.2	5.1	5.133	0.058	0.020	0.020	5.113
Middle	-3 to -4	5.2	5.2	5.2	5.200	0.000	0.100	0.100	5.100
Middle	-4 to -5	5.2	5.1	5.1	5.133	0.058	0.027	0.027	5.107
Right	-5 to -6	5	5	5	5.000	0.000	0.077	-0.077	5.077
Right	-6 to -7	5.1	5.1	5.1	5.100	0.000	0.087	-0.087	5.187
Right	-7 to -8	5.3	5.3	5.2	5.267	0.058	0.037	0.037	5.230
Right	-8 to -9	5.1	5.1	5.2	5.133	0.058	0.017	0.017	5.117
Right	-9 to -10	5.1	5.1	5.1	5.100	0.000	0.077	-0.077	5.177
Right	-10 to -11	5.1	5	5.1	5.067	0.058	0.033	-0.033	5.100
Right	-11 to -12	5.1	5.2	5.2	5.167	0.058	0.080	-0.080	5.247
Right	-12 to -13	5.1	5.1	5.1	5.100	0.000	0.173	-0.173	5.273
Right	-13 to -14	5.2	5.2	5.1	5.167	0.058	0.017	-0.017	5.183
					Overall Avg		0.051	-0.029	
					Left Avg		0.022		
					Middle Avg		0.050		
					Right Avg		0.066		
					Overall SD		0.040	0.059	
					Left SD		0.030		
					Middle SD		0.035		
					Right SD		0.049		

TABLE 30.--Measurement Accuracy of a 6 cm, 20 sec, 0.4 mm Voxel Denex Maxillary Scan for Depth

Third	Points	T1	T2	T3	CB Mean	SD	Abs Diff	CBCT-DIR	DIR Mean
Front	14 to 15	5.1	5.1	5.1	5.100	0.000	0.150	-0.150	5.250
Front	13 to 14	5.2	5.1	5.1	5.133	0.058	0.010	0.010	5.123
Front	12 to 13	5.1	5	5	5.033	0.058	0.103	-0.103	5.137
Front	11 to 12	5.1	5.1	5.1	5.100	0.000	0.090	-0.090	5.190
Front	10 to 11	5.1	5.2	5.2	5.167	0.058	0.093	-0.093	5.260
Front	9 to 10	5.1	5.2	5.2	5.167	0.058	0.017	0.017	5.150
Front	8 to 9	5	5	5.1	5.033	0.058	0.033	-0.033	5.067
Front	7 to 8	5	5.1	5.1	5.067	0.058	0.117	-0.117	5.183
Front	6 to 7	5.2	5.2	5.2	5.200	0.000	0.067	-0.067	5.267
Front	5 to 6	5	5	4.9	4.967	0.058	0.067	-0.067	5.033
Middle	4 to 5	4.9	4.9	5	4.933	0.058	0.103	-0.103	5.037
Middle	3 to 4	5.3	5.3	5.3	5.300	0.000	0.007	0.007	5.293
Middle	2 to 3	5	4.9	4.9	4.933	0.058	0.113	-0.113	5.047
Middle	1 to 2	5.1	5.2	5.2	5.167	0.058	0.007	0.007	5.160
Middle	0 to 1	5.1	5.1	5.1	5.100	0.000	0.087	0.087	5.013
Middle	0 to -1	5	4.9	4.9	4.933	0.058	0.173	-0.173	5.107
Middle	-1 to -2	5.3	5.4	5.3	5.333	0.058	0.100	0.100	5.233
Middle	-2 to -3	5	5.1	5	5.033	0.058	0.017	-0.017	5.050
Middle	-3 to -4	5.2	5.3	5.2	5.233	0.058	0.003	0.003	5.230
Middle	-4 to -5	5.1	5.1	5	5.067	0.058	0.043	-0.043	5.110
Back	-5 to -6	5.1	5.1	5.1	5.100	0.000	0.043	-0.043	5.143
Back	-6 to -7	5.2	5.1	5.1	5.133	0.058	0.050	-0.050	5.183
Back	-7 to -8	5.1	5	5.1	5.067	0.058	0.090	-0.090	5.157
Back	-8 to -9	5	5	5.1	5.033	0.058	0.103	-0.103	5.137
Back	-9 to -10	5.2	5.3	5.3	5.267	0.058	0.003	0.003	5.263
Back	-10 to -11	5.1	4.9	5	5.000	0.100	0.083	-0.083	5.083
Back	-11 to -12	5.1	5.2	5.2	5.167	0.058	0.103	-0.103	5.270
Back	-12 to -13	5.1	5	5	5.033	0.058	0.050	-0.050	5.083
Back	-13 to -14	5.1	5.1	5.1	5.100	0.000	0.090	-0.090	5.190
Back	-14 to -15	5.1	5.2	5.2	5.167	0.058	0.037	0.037	5.130
Back	-15 to -16	5.2	5.2	5.3	5.233	0.058	0.063	-0.063	5.297
					Overall Avg		0.068	-0.051	
					Front Avg		0.108		
					Middle Avg		0.073		
					Back Avg		0.053		
					Overall SD		0.045	0.064	
					Front SD		0.045		
					Middle SD		0.058		
					Back SD		0.032		

TABLE 31.--Measurement Accuracy of a 6 cm, 10 sec, 0.4 mm Voxel Scan for Height

Third	Points	T1	T2	T3	CB Mean	SD	Abs Diff	CBCT-DIR	DIR Mean
Top	4 to 5	5.1	5.1	5.1	5.100	0.000	0.037	0.037	5.063
Top	3 to 4	5.1	5.2	5.2	5.167	0.058	0.050	-0.050	5.217
Top	2 to 3	5	5.1	5	5.033	0.058	0.073	-0.073	5.107
Middle	1 to 2	5.2	5.2	5.2	5.200	0.000	0.003	-0.003	5.203
Middle	0 to 1	5.2	5.2	5.2	5.200	0.000	0.213	0.213	4.987
Middle	0 to -1	5	5.1	5	5.033	0.058	0.137	-0.137	5.170
Middle	-1 to -2	5.2	5.2	5.2	5.200	0.000	0.053	0.053	5.147
Bottom	-2 to -3	5	5.1	5	5.033	0.058	0.020	-0.020	5.053
Bottom	-3 to -4	5.3	5.2	5.2	5.233	0.058	0.010	0.010	5.223
Bottom	-4 to -5	5.2	5.2	5.2	5.200	0.000	0.050	0.050	5.150
					Overall Avg		0.065	0.008	
					Top Avg		0.055		
					Middle Avg		0.028		
					Bottom Avg		0.035		
					Overall SD		0.065	0.093	
					Top SD		0.019		
					Middle SD		0.093		
					Bottom SD		0.021		

TABLE 32.--Measurement Accuracy of a 6 cm, 10 sec, 0.4 mm Voxel Scan for Width

Third	Points	T1	T2	T3	CB Mean	SD	Abs Diff	CBCT-DIR	DIR Mean
Left	15 to 16	5.1	5.2	5.1	5.133	0.058	0.047	0.047	5.087
Left	14 to 15	5.2	5.2	5.2	5.200	0.000	0.003	0.003	5.197
Left	13 to 14	5.1	5.1	5.1	5.100	0.000	0.020	-0.020	5.120
Left	12 to 13	5.2	5.1	5.2	5.167	0.058	0.047	-0.047	5.213
Left	11 to 12	5.1	5.2	5.1	5.133	0.058	0.003	0.003	5.130
Left	10 to 11	5.2	5.2	5.1	5.167	0.058	0.037	-0.037	5.203
Left	9 to 10	5.2	5.1	5.2	5.167	0.058	0.003	0.003	5.163
Left	8 to 9	5	5.1	5.1	5.067	0.058	0.113	-0.113	5.180
Left	7 to 8	5.1	5.2	5.2	5.167	0.058	0.017	0.017	5.150
Left	6 to 7	5	5	5	5.000	0.000	0.060	-0.060	5.060
Left	5 to 6	5.2	5.2	5.2	5.200	0.000	0.023	-0.023	5.223
Middle	4 to 5	5.1	5.2	5.1	5.133	0.058	0.040	-0.040	5.173
Middle	3 to 4	4.9	4.9	5	4.933	0.058	0.013	-0.013	4.947
Middle	2 to 3	5.6	5.6	5.7	5.633	0.058	0.003	-0.003	5.637
Middle	1 to 2	4.7	4.7	4.7	4.700	0.000	0.153	-0.153	4.853
Middle	0 to 1	4.5	4.5	4.5	4.500	0.000	0.030	-0.030	4.530
Middle	0 to -1	5.9	5.9	5.8	5.867	0.058	0.133	-0.133	6.000
Middle	-1 to -2	5.2	5.2	5.2	5.200	0.000	0.150	-0.150	5.350
Middle	-2 to -3	5.1	5.2	5.2	5.167	0.058	0.053	0.053	5.113
Middle	-3 to -4	5.1	5.2	5.2	5.167	0.058	0.067	0.067	5.100
Middle	-4 to -5	5	5.1	5	5.033	0.058	0.073	-0.073	5.107
Right	-5 to -6	5	5	5	5.000	0.000	0.077	-0.077	5.077
Right	-6 to -7	5.2	5.2	5	5.133	0.115	0.053	-0.053	5.187
Right	-7 to -8	5.2	5.2	5.2	5.200	0.000	0.030	-0.030	5.230
Right	-8 to -9	5.1	5.1	5.1	5.100	0.000	0.017	-0.017	5.117
Right	-9 to -10	5.2	5.3	5.2	5.233	0.058	0.057	0.057	5.177
Right	-10 to -11	5	5	5	5.000	0.000	0.100	-0.100	5.100
Right	-11 to -12	5.3	5.2	5.3	5.267	0.058	0.020	0.020	5.247
Right	-12 to -13	5.2	5.2	5.2	5.200	0.000	0.073	-0.073	5.273
Right	-13 to -14	5.1	5	5.2	5.100	0.100	0.083	-0.083	5.183
					Overall Avg		0.053	-0.035	
					Left Avg		0.035		
					Middle Avg		0.057		
					Right Avg		0.057		
					Overall SD		0.043	0.059	
					Left SD		0.033		
					Middle SD		0.056		
					Right SD		0.029		

TABLE 33.--Measurement Accuracy of a 6 cm, 10 sec, 0.4 mm Voxel Scan for Depth

Third	Points	T1	T2	T3	CB Mean	SD	Abs Diff	CBCT-DIR	DIR Mean
Front	14 to 15	5.1	5.2	5.2	5.167	0.058	0.083	-0.083	5.250
Front	13 to 14	5.1	5.1	5	5.067	0.058	0.057	-0.057	5.123
Front	12 to 13	5	5	5.1	5.033	0.058	0.103	-0.103	5.137
Front	11 to 12	5.1	5.1	5	5.067	0.058	0.123	-0.123	5.190
Front	10 to 11	5.2	5.3	5.1	5.200	0.100	0.060	-0.060	5.260
Front	9 to 10	5	5.2	5.2	5.133	0.115	0.017	-0.017	5.150
Front	8 to 9	5	5.1	5.1	5.067	0.058	0.000	0.000	5.067
Front	7 to 8	5.1	5.2	5.2	5.167	0.058	0.017	-0.017	5.183
Front	6 to 7	5.3	5.1	5.2	5.200	0.100	0.067	-0.067	5.267
Front	5 to 6	5.1	5	5.1	5.067	0.058	0.033	0.033	5.033
Middle	4 to 5	5	5	5	5.000	0.000	0.037	-0.037	5.037
Middle	3 to 4	5.2	5.3	5.2	5.233	0.058	0.060	-0.060	5.293
Middle	2 to 3	5	5	5	5.000	0.000	0.047	-0.047	5.047
Middle	1 to 2	5.1	5.2	5.2	5.167	0.058	0.007	0.007	5.160
Middle	0 to 1	5.2	5.1	5.2	5.167	0.058	0.153	0.153	5.013
Middle	0 to -1	4.9	5	4.9	4.933	0.058	0.173	-0.173	5.107
Middle	-1 to -2	5.3	5.4	5.3	5.333	0.058	0.100	0.100	5.233
Middle	-2 to -3	5.1	5.1	5	5.067	0.058	0.017	0.017	5.050
Middle	-3 to -4	5.2	5.3	5.3	5.267	0.058	0.037	0.037	5.230
Middle	-4 to -5	5.1	5	5.1	5.067	0.058	0.043	-0.043	5.110
Back	-5 to -6	5.2	5.2	5.2	5.200	0.000	0.057	0.057	5.143
Back	-6 to -7	5.1	5.1	5.2	5.133	0.058	0.050	-0.050	5.183
Back	-7 to -8	5.2	5	5	5.067	0.115	0.090	-0.090	5.157
Back	-8 to -9	5.2	5.2	5.2	5.200	0.000	0.063	0.063	5.137
Back	-9 to -10	5.3	5.3	5.2	5.267	0.058	0.003	0.003	5.263
Back	-10 to -11	5	5	5.1	5.033	0.058	0.050	-0.050	5.083
Back	-11 to -12	5.2	5.2	5.2	5.200	0.000	0.070	-0.070	5.270
Back	-12 to -13	5.1	5	5	5.033	0.058	0.050	-0.050	5.083
Back	-13 to -14	5.2	5	5	5.067	0.115	0.123	-0.123	5.190
Back	-14 to -15	5.2	5.1	5.1	5.133	0.058	0.003	0.003	5.130
Back	-15 to -16	5.2	5.1	5.1	5.133	0.058	0.163	-0.163	5.297
					Overall Avg		0.063	-0.033	
					Front Avg		0.058		
					Middle Avg		0.040		
					Back Avg		0.110		
					Overall SD		0.047	0.072	
					Front SD		0.040		
					Middle SD		0.057		
					Back SD		0.047		

TABLE 34.--Measurement Accuracy of a 6 cm, 10 sec, 0.3 mm Voxel Scan for Height

Third	Points	T1	T2	T3	CB Mean	SD	Abs Diff	CBCT-DIR	DIR Mean
Top	4 to 5	5.05	5.05	5	5.033	0.029	0.030	-0.030	5.063
Top	3 to 4	5.14	5.15	5.1	5.130	0.026	0.087	-0.087	5.217
Top	2 to 3	5.05	5	4.95	5.000	0.050	0.107	-0.107	5.107
Middle	1 to 2	5.14	5.19	5.14	5.157	0.029	0.047	-0.047	5.203
Middle	0 to 1	5.1	5.14	5.05	5.097	0.045	0.110	0.110	4.987
Middle	0 to -1	5.1	5.05	5.05	5.067	0.029	0.103	-0.103	5.170
Middle	-1 to -2	5.1	5.15	5.24	5.163	0.071	0.017	0.017	5.147
Bottom	-2 to -3	4.95	5	4.95	4.967	0.029	0.087	-0.087	5.053
Bottom	-3 to -4	5.19	5.24	5.25	5.227	0.032	0.003	0.003	5.223
Bottom	-4 to -5	5.14	5.19	5.19	5.173	0.029	0.023	0.023	5.150
					Overall Avg		0.061	-0.031	
					Top Avg		0.068		
					Middle Avg		0.032		
					Bottom Avg		0.055		
					Overall SD		0.041	0.070	
					Top SD		0.040		
					Middle SD		0.045		
					Bottom SD		0.044		

TABLE 35.--Measurement Accuracy of a 6 cm, 10 sec, 0.3 mm Voxel Scan for Width

Third	Points	T1	T2	T3	CB Mean	SD	Abs Diff	CBCT-DIR	DIR Mean
Left	15 to 16	5.13	5.12	5.13	5.127	0.006	0.040	0.040	5.087
Left	14 to 15	5.19	5.13	5.19	5.170	0.035	0.027	-0.027	5.197
Left	13 to 14	4.98	5.05	5.11	5.047	0.065	0.073	-0.073	5.120
Left	12 to 13	5.21	5.15	5.29	5.217	0.070	0.003	0.003	5.213
Left	11 to 12	5.04	5.05	5.11	5.067	0.038	0.063	-0.063	5.130
Left	10 to 11	5.18	5.12	5.18	5.160	0.035	0.043	-0.043	5.203
Left	9 to 10	5.12	5.12	5.18	5.140	0.035	0.023	-0.023	5.163
Left	8 to 9	5.19	5.12	5.13	5.147	0.038	0.033	-0.033	5.180
Left	7 to 8	5.04	5.11	5.18	5.110	0.070	0.040	-0.040	5.150
Left	6 to 7	5.01	5.02	5.01	5.013	0.006	0.047	-0.047	5.060
Left	5 to 6	5.25	5.18	5.12	5.183	0.065	0.040	-0.040	5.223
Middle	4 to 5	5.18	5.18	5.18	5.180	0.000	0.007	0.007	5.173
Middle	3 to 4	4.92	4.86	4.86	4.880	0.035	0.067	-0.067	4.947
Middle	2 to 3	5.58	5.65	5.65	5.627	0.040	0.010	-0.010	5.637
Middle	1 to 2	4.79	4.74	4.72	4.750	0.036	0.103	-0.103	4.853
Middle	0 to 1	4.33	4.27	4.34	4.313	0.038	0.217	-0.217	4.530
Middle	0 to -1	5.97	6.04	5.97	5.993	0.040	0.007	-0.007	6.000
Middle	-1 to -2	5.32	5.31	5.31	5.313	0.006	0.037	-0.037	5.350
Middle	-2 to -3	5.11	5.18	5.12	5.137	0.038	0.023	0.023	5.113
Middle	-3 to -4	5.13	5.13	5.12	5.127	0.006	0.027	0.027	5.100
Middle	-4 to -5	5.2	5.19	5.13	5.173	0.038	0.067	0.067	5.107
Right	-5 to -6	4.98	4.98	4.99	4.983	0.006	0.093	-0.093	5.077
Right	-6 to -7	5.12	5.13	5.19	5.147	0.038	0.040	-0.040	5.187
Right	-7 to -8	5.25	5.25	5.18	5.227	0.040	0.003	-0.003	5.230
Right	-8 to -9	5.25	5.18	5.18	5.203	0.040	0.087	0.087	5.117
Right	-9 to -10	5.22	5.29	5.21	5.240	0.044	0.063	0.063	5.177
Right	-10 to -11	4.98	4.92	4.98	4.960	0.035	0.140	-0.140	5.100
Right	-11 to -12	5.15	5.22	5.15	5.173	0.040	0.073	-0.073	5.247
Right	-12 to -13	5.14	5.2	5.2	5.180	0.035	0.093	-0.093	5.273
Right	-13 to -14	5.12	5.18	5.11	5.137	0.038	0.047	-0.047	5.183
					Overall Avg		0.055	-0.033	
					Left Avg		0.040		
					Middle Avg		0.037		
					Right Avg		0.071		
					Overall SD		0.045	0.063	
					Left SD		0.019		
					Middle SD		0.065		
					Right SD		0.039		

TABLE 36.--Measurement Accuracy of a 6 cm, 10 sec, 0.3 mm Voxel Scan for Depth

Third	Points	T1	T2	T3	CB Mean	SD	Abs Diff	CBCT-DIR	DIR Mean
Front	14 to 15	5.19	5.13	5.25	5.190	0.060	0.060	-0.060	5.250
Front	13 to 14	5.06	5.18	5.05	5.097	0.072	0.027	-0.027	5.123
Front	12 to 13	5.11	5.05	5.11	5.090	0.035	0.047	-0.047	5.137
Front	11 to 12	5.19	5.13	5.25	5.190	0.060	0.000	0.000	5.190
Front	10 to 11	5.11	5.12	5.18	5.137	0.038	0.123	-0.123	5.260
Front	9 to 10	5.05	5.11	5.19	5.117	0.070	0.033	-0.033	5.150
Front	8 to 9	4.92	4.98	4.98	4.960	0.035	0.107	-0.107	5.067
Front	7 to 8	5.25	5.18	5.25	5.227	0.040	0.043	0.043	5.183
Front	6 to 7	5.11	5.18	5.11	5.133	0.040	0.133	-0.133	5.267
Front	5 to 6	4.98	5.05	5.05	5.027	0.040	0.007	-0.007	5.033
Middle	4 to 5	5.05	4.98	5.05	5.027	0.040	0.010	-0.010	5.037
Middle	3 to 4	5.25	5.32	5.25	5.273	0.040	0.020	-0.020	5.293
Middle	2 to 3	4.93	5.06	4.99	4.993	0.065	0.053	-0.053	5.047
Middle	1 to 2	5.05	5.11	5.18	5.113	0.065	0.047	-0.047	5.160
Middle	0 to 1	5	5.02	5.06	5.027	0.031	0.013	0.013	5.013
Middle	0 to -1	5.18	5.18	5.05	5.137	0.075	0.030	0.030	5.107
Middle	-1 to -2	5.31	5.45	5.38	5.380	0.070	0.147	0.147	5.233
Middle	-2 to -3	5.11	5.05	5.05	5.070	0.035	0.020	0.020	5.050
Middle	-3 to -4	5.19	5.19	5.32	5.233	0.075	0.003	0.003	5.230
Middle	-4 to -5	5.18	5.11	5.18	5.157	0.040	0.047	0.047	5.110
Back	-5 to -6	5.12	5.12	5.19	5.143	0.040	0.000	0.000	5.143
Back	-6 to -7	5.32	5.25	5.31	5.293	0.038	0.110	0.110	5.183
Back	-7 to -8	5.05	5.18	5.11	5.113	0.065	0.043	-0.043	5.157
Back	-8 to -9	5.19	5.19	5.19	5.190	0.000	0.053	0.053	5.137
Back	-9 to -10	5.25	5.25	5.31	5.270	0.035	0.007	0.007	5.263
Back	-10 to -11	4.98	5.05	5.05	5.027	0.040	0.057	-0.057	5.083
Back	-11 to -12	5.18	5.18	5.18	5.180	0.000	0.090	-0.090	5.270
Back	-12 to -13	5.12	4.98	4.91	5.003	0.107	0.080	-0.080	5.083
Back	-13 to -14	4.98	5.06	5.11	5.050	0.066	0.140	-0.140	5.190
Back	-14 to -15	5.05	5.19	5.12	5.120	0.070	0.010	-0.010	5.130
Back	-15 to -16	5.11	5.25	5.11	5.157	0.081	0.140	-0.140	5.297
					Overall Avg		0.055	-0.024	
					Front Avg		0.033		
					Middle Avg		0.028		
					Back Avg		0.070		
					Overall SD		0.047	0.068	
					Front SD		0.047		
					Middle SD		0.041		
					Back SD		0.050		

TABLE 37.--Measurement Accuracy of a 6 cm, 40 sec, 0.2 mm Voxel Mandibular Scan for Height

Third	Points	T1	T2	T3	CB Mean	SD	Abs Diff	CBCT-DIR	DIR Mean
Top	4 to 5	5.05	5.09	5.05	5.063	0.023	0.000	0.000	5.063
Top	3 to 4	5.13	5.17	5.17	5.157	0.023	0.060	-0.060	5.217
Top	2 to 3	5.01	5.05	5.01	5.023	0.023	0.083	-0.083	5.107
Middle	1 to 2	5.13	5.17	5.18	5.160	0.026	0.043	-0.043	5.203
Middle	0 to 1	5.13	5.13	5.17	5.143	0.023	0.157	0.157	4.987
Middle	0 to -1	5.01	5.01	5.01	5.010	0.000	0.160	-0.160	5.170
Middle	-1 to -2	5.17	5.17	5.17	5.170	0.000	0.023	0.023	5.147
Bottom	-2 to -3	5.05	5.05	5.05	5.050	0.000	0.003	-0.003	5.053
Bottom	-3 to -4	5.22	5.26	5.21	5.230	0.026	0.007	0.007	5.223
Bottom	-4 to -5	5.21	5.17	5.21	5.197	0.023	0.047	0.047	5.150
					Overall Avg		0.058	-0.012	
					Top Avg		0.042		
					Middle Avg		0.033		
					Bottom Avg		0.025		
					Overall SD		0.059	0.084	
					Top SD		0.043		
					Middle SD		0.073		
					Bottom SD		0.024		

TABLE 38.--Measurement Accuracy of a 6 cm, 40 sec, 0.2 mm Voxel Mandibular Scan for Width

Third	Points	T1	T2	T3	CB Mean	SD	Abs Diff	CBCT-DIR	DIR Mean
Left	15 to 16	5.17	5.17	5.07	5.137	0.058	0.050	0.050	5.087
Left	14 to 15	5.07	5.2	5.16	5.143	0.067	0.053	-0.053	5.197
Left	13 to 14	5.06	5.15	5.06	5.090	0.052	0.030	-0.030	5.120
Left	12 to 13	5.18	5.21	5.17	5.187	0.021	0.027	-0.027	5.213
Left	11 to 12	5.16	5.11	5.2	5.157	0.045	0.027	0.027	5.130
Left	10 to 11	5.14	5.24	5.18	5.187	0.050	0.017	-0.017	5.203
Left	9 to 10	5.07	5.11	5.07	5.083	0.023	0.080	-0.080	5.163
Left	8 to 9	4.99	5.11	5.12	5.073	0.072	0.107	-0.107	5.180
Left	7 to 8	5.05	5.1	5.14	5.097	0.045	0.053	-0.053	5.150
Left	6 to 7	5.18	5.04	4.98	5.067	0.103	0.007	0.007	5.060
Left	5 to 6	5.16	5.17	5.12	5.150	0.026	0.073	-0.073	5.223
Middle	4 to 5	5.21	5.18	5.09	5.160	0.062	0.013	-0.013	5.173
Middle	3 to 4	4.92	4.88	4.87	4.890	0.026	0.057	-0.057	4.947
Middle	2 to 3	5.48	5.45	5.5	5.477	0.025	0.160	-0.160	5.637
Middle	1 to 2	4.75	4.78	4.68	4.737	0.051	0.117	-0.117	4.853
Middle	0 to 1	4.5	4.43	4.43	4.453	0.040	0.077	-0.077	4.530
Middle	0 to -1	5.97	5.88	5.92	5.923	0.045	0.077	-0.077	6.000
Middle	-1 to -2	5.34	5.34	5.3	5.327	0.023	0.023	-0.023	5.350
Middle	-2 to -3	5.06	5.02	5.06	5.047	0.023	0.067	-0.067	5.113
Middle	-3 to -4	5.22	5.18	5.14	5.180	0.040	0.080	0.080	5.100
Middle	-4 to -5	5.07	5.07	5.11	5.083	0.023	0.023	-0.023	5.107
Right	-5 to -6	4.95	4.95	4.95	4.950	0.000	0.127	-0.127	5.077
Right	-6 to -7	5.12	5.18	5.13	5.143	0.032	0.043	-0.043	5.187
Right	-7 to -8	5.16	5.16	5.24	5.187	0.046	0.043	-0.043	5.230
Right	-8 to -9	5.12	5.09	5.03	5.080	0.046	0.037	-0.037	5.117
Right	-9 to -10	5.19	5.17	5.17	5.177	0.012	0.000	0.000	5.177
Right	-10 to -11	5.05	5	5.05	5.033	0.029	0.067	-0.067	5.100
Right	-11 to -12	5.05	5.14	5.15	5.113	0.055	0.133	-0.133	5.247
Right	-12 to -13	5.29	5.16	5.18	5.210	0.070	0.063	-0.063	5.273
Right	-13 to -14	5.22	5.19	5.23	5.213	0.021	0.030	0.030	5.183
					Overall Avg		0.059	-0.046	
					Left Avg		0.062		
					Middle Avg		0.018		
					Right Avg		0.060		
					Overall SD		0.040	0.054	
					Left SD		0.030		
					Middle SD		0.045		
					Right SD		0.044		

TABLE 39.--Measurement Accuracy of a 6 cm, 40 sec, 0.2 mm Voxel Mandibular Scan for Depth

Third	Points	T1	T2	T3	CB Mean	SD	Abs Diff	CBCT-DIR	DIR Mean
Front	14 to 15	5.19	5.12	5.19	5.167	0.040	0.083	-0.083	5.250
Front	13 to 14	5.12	5.03	5.03	5.060	0.052	0.063	-0.063	5.123
Front	12 to 13	5.07	5.06	5.07	5.067	0.006	0.070	-0.070	5.137
Front	11 to 12	5.15	5.06	5.11	5.107	0.045	0.083	-0.083	5.190
Front	10 to 11	5.16	5.2	5.2	5.187	0.023	0.073	-0.073	5.260
Front	9 to 10	4.99	5.07	5.03	5.030	0.040	0.120	-0.120	5.150
Front	8 to 9	5.02	5.06	4.98	5.020	0.040	0.047	-0.047	5.067
Front	7 to 8	5.17	5.07	5.09	5.110	0.053	0.073	-0.073	5.183
Front	6 to 7	5.15	5.28	5.15	5.193	0.075	0.073	-0.073	5.267
Front	5 to 6	4.98	5.07	5.07	5.040	0.052	0.007	0.007	5.033
Middle	4 to 5	4.98	5.02	4.93	4.977	0.045	0.060	-0.060	5.037
Middle	3 to 4	5.37	5.24	5.2	5.270	0.089	0.023	-0.023	5.293
Middle	2 to 3	4.95	5	4.99	4.980	0.026	0.067	-0.067	5.047
Middle	1 to 2	5.14	5.18	5.19	5.170	0.026	0.010	0.010	5.160
Middle	0 to 1	5.09	5.08	5.09	5.087	0.006	0.073	0.073	5.013
Middle	0 to -1	5.02	4.98	4.97	4.990	0.026	0.117	-0.117	5.107
Middle	-1 to -2	5.28	5.25	5.28	5.270	0.017	0.037	0.037	5.233
Middle	-2 to -3	5.07	4.94	5.06	5.023	0.072	0.027	-0.027	5.050
Middle	-3 to -4	5.17	5.2	5.17	5.180	0.017	0.050	-0.050	5.230
Middle	-4 to -5	5.02	5.11	5.02	5.050	0.052	0.060	-0.060	5.110
Back	-5 to -6	5.13	5.09	5.13	5.117	0.023	0.027	-0.027	5.143
Back	-6 to -7	5.06	5.2	5.15	5.137	0.071	0.047	-0.047	5.183
Back	-7 to -8	4.98	5.02	5.1	5.033	0.061	0.123	-0.123	5.157
Back	-8 to -9	5.12	5.15	5.11	5.127	0.021	0.010	-0.010	5.137
Back	-9 to -10	5.25	5.29	5.24	5.260	0.026	0.003	-0.003	5.263
Back	-10 to -11	5.03	5.03	5.07	5.043	0.023	0.040	-0.040	5.083
Back	-11 to -12	5.15	5.24	5.24	5.210	0.052	0.060	-0.060	5.270
Back	-12 to -13	5.06	4.97	4.98	5.003	0.049	0.080	-0.080	5.083
Back	-13 to -14	5.13	5.13	4.99	5.083	0.081	0.107	-0.107	5.190
Back	-14 to -15	4.98	5.08	5.06	5.040	0.053	0.090	-0.090	5.130
Back	-15 to -16	5.27	5.25	5.36	5.293	0.059	0.003	-0.003	5.297
					Overall Avg		0.058	-0.050	
					Front Avg		0.045		
					Middle Avg		0.060		
					Back Avg		0.015		
					Overall SD		0.034	0.046	
					Front SD		0.029		
					Middle SD		0.031		
					Back SD		0.042		

TABLE 40.--Measurement Accuracy of a 6 cm, 40 sec, 0.2 mm Voxel Maxillary Scan for Height

Third	Points	T1	T2	T3	CB Mean	SD	Abs Diff	CBCT-DIR	DIR Mean
Top	4 to 5	5	5	5.04	5.013	0.023	0.050	-0.050	5.063
Top	3 to 4	5.2	5.12	5.2	5.173	0.046	0.043	-0.043	5.217
Top	2 to 3	5	4.96	4.96	4.973	0.023	0.133	-0.133	5.107
Middle	1 to 2	5.16	5.12	5.16	5.147	0.023	0.057	-0.057	5.203
Middle	0 to 1	5.12	5.16	5.16	5.147	0.023	0.160	0.160	4.987
Middle	0 to -1	5	4.96	5	4.987	0.023	0.183	-0.183	5.170
Middle	-1 to -2	5.16	5.16	5.16	5.160	0.000	0.013	0.013	5.147
Bottom	-2 to -3	5.04	5.04	5	5.027	0.023	0.027	-0.027	5.053
Bottom	-3 to -4	5.24	5.12	5.16	5.173	0.061	0.050	-0.050	5.223
Bottom	-4 to -5	5.16	5.16	5.16	5.160	0.000	0.010	0.010	5.150
					Overall Avg		0.073	-0.036	
					Top Avg		0.092		
					Middle Avg		0.035		
					Bottom Avg		0.018		
					Overall SD		0.063	0.091	
					Top SD		0.050		
					Middle SD		0.081		
					Bottom SD		0.020		

TABLE 41.--Measurement Accuracy of a 6 cm, 40 sec, 0.2 mm Voxel Maxillary Scan for Width

Third	Points	T1	T2	T3	CB Mean	SD	Abs Diff	CBCT-DIR	DIR Mean
Left	15 to 16	5.12	5.11	5.09	5.107	0.015	0.020	0.020	5.087
Left	14 to 15	5.18	5.24	5.19	5.203	0.032	0.007	0.007	5.197
Left	13 to 14	5.03	5.11	5.09	5.077	0.042	0.043	-0.043	5.120
Left	12 to 13	5.2	5.21	5.21	5.207	0.006	0.007	-0.007	5.213
Left	11 to 12	5.1	5.17	5.09	5.120	0.044	0.010	-0.010	5.130
Left	10 to 11	5.11	5.19	5.14	5.147	0.040	0.057	-0.057	5.203
Left	9 to 10	5.03	5.04	5.09	5.053	0.032	0.110	-0.110	5.163
Left	8 to 9	5.13	5.05	5.11	5.097	0.042	0.083	-0.083	5.180
Left	7 to 8	5.02	5.1	5.03	5.050	0.044	0.100	-0.100	5.150
Left	6 to 7	4.99	4.98	4.97	4.980	0.010	0.080	-0.080	5.060
Left	5 to 6	5.11	5.11	5.09	5.103	0.012	0.120	-0.120	5.223
Middle	4 to 5	5.1	5.17	5.03	5.100	0.070	0.073	-0.073	5.173
Middle	3 to 4	4.89	4.8	4.91	4.867	0.059	0.080	-0.080	4.947
Middle	2 to 3	5.56	5.56	5.55	5.557	0.006	0.080	-0.080	5.637
Middle	1 to 2	4.73	4.73	4.63	4.697	0.058	0.157	-0.157	4.853
Middle	0 to 1	4.36	4.46	4.42	4.413	0.050	0.117	-0.117	4.530
Middle	0 to -1	5.92	5.96	5.95	5.943	0.021	0.057	-0.057	6.000
Middle	-1 to -2	5.24	5.17	5.31	5.240	0.070	0.110	-0.110	5.350
Middle	-2 to -3	5.2	5.06	5.06	5.107	0.081	0.007	-0.007	5.113
Middle	-3 to -4	5.12	5.2	5.06	5.127	0.070	0.027	0.027	5.100
Middle	-4 to -5	5.11	5.2	5.15	5.153	0.045	0.047	0.047	5.107
Right	-5 to -6	4.95	4.91	5.01	4.957	0.050	0.120	-0.120	5.077
Right	-6 to -7	5.11	5.06	5.15	5.107	0.045	0.080	-0.080	5.187
Right	-7 to -8	5.26	5.23	5.27	5.253	0.021	0.023	0.023	5.230
Right	-8 to -9	5.03	5.05	5.05	5.043	0.012	0.073	-0.073	5.117
Right	-9 to -10	5.13	5.19	5.06	5.127	0.065	0.050	-0.050	5.177
Right	-10 to -11	5.03	5.04	4.94	5.003	0.055	0.097	-0.097	5.100
Right	-11 to -12	5.2	5.11	5.15	5.153	0.045	0.093	-0.093	5.247
Right	-12 to -13	5.18	5.1	5.1	5.127	0.046	0.147	-0.147	5.273
Right	-13 to -14	5.11	5.13	5.22	5.153	0.059	0.030	-0.030	5.183
					Overall Avg		0.070	-0.062	
					Left Avg		0.070		
					Middle Avg		0.060		
					Right Avg		0.079		
					Overall SD		0.042	0.054	
					Left SD		0.043		
					Middle SD		0.045		
					Right SD		0.041		

TABLE 42.--Measurement Accuracy of a 6 cm, 40 sec, 0.2 mm Voxel Maxillary Scan for Depth

Third	Points	T1	T2	T3	CB Mean	SD	Abs Diff	CBCT-DIR	DIR Mean
Front	14 to 15	5.17	5.13	5.18	5.160	0.026	0.090	-0.090	5.250
Front	13 to 14	5	5.04	5.04	5.027	0.023	0.097	-0.097	5.123
Front	12 to 13	5.09	5.04	5.09	5.073	0.029	0.063	-0.063	5.137
Front	11 to 12	5.09	5.09	5.13	5.103	0.023	0.087	-0.087	5.190
Front	10 to 11	5.19	5.14	5.18	5.170	0.026	0.090	-0.090	5.260
Front	9 to 10	5	5.14	5.13	5.090	0.078	0.060	-0.060	5.150
Front	8 to 9	5	4.99	5.09	5.027	0.055	0.040	-0.040	5.067
Front	7 to 8	5.15	5.12	5.1	5.123	0.025	0.060	-0.060	5.183
Front	6 to 7	5.18	5.23	5.22	5.210	0.026	0.057	-0.057	5.267
Front	5 to 6	5.09	5	5	5.030	0.052	0.003	-0.003	5.033
Middle	4 to 5	4.99	4.95	4.86	4.933	0.067	0.103	-0.103	5.037
Middle	3 to 4	5.27	5.36	5.18	5.270	0.090	0.023	-0.023	5.293
Middle	2 to 3	5	4.96	5.01	4.990	0.026	0.057	-0.057	5.047
Middle	1 to 2	5.09	5.13	5.04	5.087	0.045	0.073	-0.073	5.160
Middle	0 to 1	5.1	5.15	5.11	5.120	0.026	0.107	0.107	5.013
Middle	0 to -1	4.99	4.95	5.08	5.007	0.067	0.100	-0.100	5.107
Middle	-1 to -2	5.27	5.28	5.37	5.307	0.055	0.073	0.073	5.233
Middle	-2 to -3	5.09	5.09	5.09	5.090	0.000	0.040	0.040	5.050
Middle	-3 to -4	5.28	5.2	5.14	5.207	0.070	0.023	-0.023	5.230
Middle	-4 to -5	5.09	4.95	5.04	5.027	0.071	0.083	-0.083	5.110
Back	-5 to -6	5.11	5.16	5.15	5.140	0.026	0.003	-0.003	5.143
Back	-6 to -7	5.14	5.09	5.14	5.123	0.029	0.060	-0.060	5.183
Back	-7 to -8	5.04	5.09	5.04	5.057	0.029	0.100	-0.100	5.157
Back	-8 to -9	5.17	5.13	5.16	5.153	0.021	0.017	0.017	5.137
Back	-9 to -10	5.22	5.18	5.27	5.223	0.045	0.040	-0.040	5.263
Back	-10 to -11	5.09	5.09	5	5.060	0.052	0.023	-0.023	5.083
Back	-11 to -12	5.18	5.18	5.14	5.167	0.023	0.103	-0.103	5.270
Back	-12 to -13	5.04	5.04	5.04	5.040	0.000	0.043	-0.043	5.083
Back	-13 to -14	5.1	5.19	5.05	5.113	0.071	0.077	-0.077	5.190
Back	-14 to -15	5.09	5.14	5.09	5.107	0.029	0.023	-0.023	5.130
Back	-15 to -16	5.18	5.27	5.23	5.227	0.045	0.070	-0.070	5.297
					Overall Avg		0.061	-0.046	
					Front Avg		0.047		
					Middle Avg		0.093		
					Back Avg		0.037		
					Overall SD		0.031	0.052	
					Front SD		0.028		
					Middle SD		0.032		
					Back SD		0.034		

TABLE 43.--Direct Digital Caliper Measurements of the CIC-Phantom for Height

Third	Points	T1	T2	T3	DIR Mean	SD
Top	10 to 11	5.12	5.11	5.14	5.123	0.015
Top	9 to 10	5.11	5.07	5.15	5.110	0.040
Top	8 to 9	5.14	5.13	5.2	5.157	0.038
Top	7 to 8	5.08	5.16	5.13	5.123	0.040
Top	6 to 7	5.12	5.15	5.23	5.167	0.057
Top	5 to 6	5.12	5.19	5.19	5.167	0.040
Top	4 to 5	5.01	5.1	5.08	5.063	0.047
Middle	3 to 4	5.24	5.19	5.22	5.217	0.025
Middle	2 to 3	5.06	5.15	5.11	5.107	0.045
Middle	1 to 2	5.16	5.23	5.22	5.203	0.038
Middle	0 to 1	4.95	5.01	5	4.987	0.032
Middle	0 to -1	5.13	5.16	5.22	5.170	0.046
Middle	-1 to -2	5.13	5.2	5.11	5.147	0.047
Middle	-2 to -3	5.02	5.09	5.05	5.053	0.035
Middle	-3 to -4	5.24	5.26	5.17	5.223	0.047
Bottom	-4 to -5	5.08	5.16	5.21	5.150	0.066
Bottom	-5 to -6	5.01	5.13	5.05	5.063	0.061
Bottom	-6 to -7	5.14	5.2	5.26	5.200	0.060
Bottom	-7 to -8	5.07	5.17	5.2	5.147	0.068
Bottom	-8 to -9	5.19	5.12	5.18	5.163	0.038
Bottom	-9 to -10	5.02	5.16	5.04	5.073	0.076
Bottom	-10 to -11	5.26	5.22	5.16	5.213	0.050
Bottom	-11 to -12	5.01	5.09	5.09	5.063	0.046
Bottom	-12 to -13	5.18	5.33	5.28	5.263	0.076

TABLE 44.--Direct Digital Caliper Measurements of the CIC-Phantom for Width

Third	Points	T1	T2	T3	DIR Mean	SD
Left	15 to 16	5.05	5.09	5.12	5.087	0.035
Left	14 to 15	5.21	5.18	5.2	5.197	0.015
Left	13 to 14	5.1	5.15	5.11	5.120	0.026
Left	12 to 13	5.22	5.14	5.28	5.213	0.070
Left	11 to 12	5.12	5.1	5.17	5.130	0.036
Left	10 to 11	5.21	5.16	5.24	5.203	0.040
Left	9 to 10	5.14	5.15	5.2	5.163	0.032
Left	8 to 9	5.14	5.22	5.18	5.180	0.040
Left	7 to 8	5.13	5.12	5.2	5.150	0.044
Left	6 to 7	5	5.07	5.11	5.060	0.056
Left	5 to 6	5.18	5.23	5.26	5.223	0.040
Middle	4 to 5	5.13	5.21	5.18	5.173	0.040
Middle	3 to 4	4.98	4.87	4.99	4.947	0.067
Middle	2 to 3	5.58	5.64	5.69	5.637	0.055
Middle	1 to 2	4.93	4.8	4.83	4.853	0.068
Middle	0 to 1	4.49	4.58	4.52	4.530	0.046
Middle	0 to -1	5.89	6.11	6	6.000	0.110
Middle	-1 to -2	5.25	5.39	5.41	5.350	0.087
Middle	-2 to -3	5.19	5.08	5.07	5.113	0.067
Middle	-3 to -4	5.12	5.05	5.13	5.100	0.044
Middle	-4 to -5	5.08	5.11	5.13	5.107	0.025
Right	-5 to -6	5.04	5.12	5.07	5.077	0.040
Right	-6 to -7	5.23	5.18	5.15	5.187	0.040
Right	-7 to -8	5.19	5.28	5.22	5.230	0.046
Right	-8 to -9	5.06	5.12	5.17	5.117	0.055
Right	-9 to -10	5.16	5.19	5.18	5.177	0.015
Right	-10 to -11	5.12	5.06	5.12	5.100	0.035
Right	-11 to -12	5.25	5.25	5.24	5.247	0.006
Right	-12 to -13	5.28	5.25	5.29	5.273	0.021
Right	-13 to -14	5.17	5.19	5.19	5.183	0.012

TABLE 45.--Direct Digital Caliper Measurements of the CIC-Phantom for Depth

Third	Points	T1	T2	T3	DIR Mean	SD
Front	14 to 15	5.23	5.28	5.24	5.250	0.026
Front	13 to 14	5.12	5.15	5.1	5.123	0.025
Front	12 to 13	5.15	5.17	5.09	5.137	0.042
Front	11 to 12	5.16	5.2	5.21	5.190	0.026
Front	10 to 11	5.24	5.24	5.3	5.260	0.035
Front	9 to 10	5.16	5.09	5.2	5.150	0.056
Front	8 to 9	5.05	5.12	5.03	5.067	0.047
Front	7 to 8	5.24	5.17	5.14	5.183	0.051
Front	6 to 7	5.29	5.23	5.28	5.267	0.032
Front	5 to 6	5.05	5.03	5.02	5.033	0.015
Middle	4 to 5	5.01	5.02	5.08	5.037	0.038
Middle	3 to 4	5.27	5.29	5.32	5.293	0.025
Middle	2 to 3	5.03	5.05	5.06	5.047	0.015
Middle	1 to 2	5.06	5.19	5.23	5.160	0.089
Middle	0 to 1	4.87	5.09	5.08	5.013	0.124
Middle	0 to -1	5.04	5.12	5.16	5.107	0.061
Middle	-1 to -2	5.27	5.25	5.18	5.233	0.047
Middle	-2 to -3	5.06	5.08	5.01	5.050	0.036
Middle	-3 to -4	5.19	5.24	5.26	5.230	0.036
Middle	-4 to -5	5.08	5.1	5.15	5.110	0.036
Back	-5 to -6	5.11	5.18	5.14	5.143	0.035
Back	-6 to -7	5.13	5.21	5.21	5.183	0.046
Back	-7 to -8	5.22	5.15	5.1	5.157	0.060
Back	-8 to -9	5.13	5.08	5.2	5.137	0.060
Back	-9 to -10	5.24	5.28	5.27	5.263	0.021
Back	-10 to -11	5.06	5.1	5.09	5.083	0.021
Back	-11 to -12	5.26	5.3	5.25	5.270	0.026
Back	-12 to -13	5.1	5.11	5.04	5.083	0.038
Back	-13 to -14	5.2	5.15	5.22	5.190	0.036
Back	-14 to -15	5.13	5.17	5.09	5.130	0.040
Back	-15 to -16	5.32	5.33	5.24	5.297	0.049

TABLE 46.--Descriptive Statistics for the Mean Absolute Differences

N	Valid	36
	Missing	0
Mean (mm)		0.06289
Median		0.06200
Std. Deviation		0.010655
Variance		0.000
Skewness		0.239
Std. Error of Skewness		0.393
Kurtosis		-0.701
Std. Error of Kurtosis		0.768
Range		0.039
Minimum		0.046
Maximum		0.085

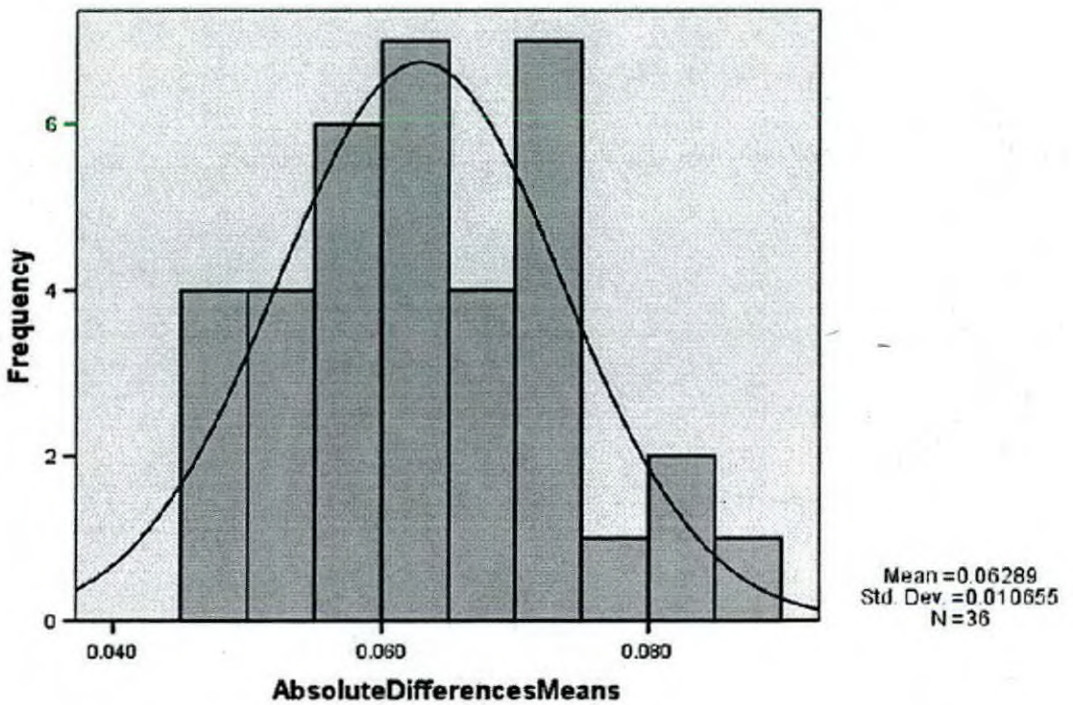


Figure 4. Evaluation of the mean absolute differences for normality. The frequency distribution indicates that the mean absolute differences are normally distributed.

TABLE 47.--Descriptive Statistics for the CBCT Measurements

N	Valid	927
	Missing	0
Mean (mm)		5.12904
Median		5.13333
Std. Deviation		0.164245
Variance		0.027
Skewness		0.719
Std. Error of Skewness		0.080
Kurtosis		10.388
Std. Error of Kurtosis		0.160
Range		1.700
Minimum		4.313
Maximum		6.013

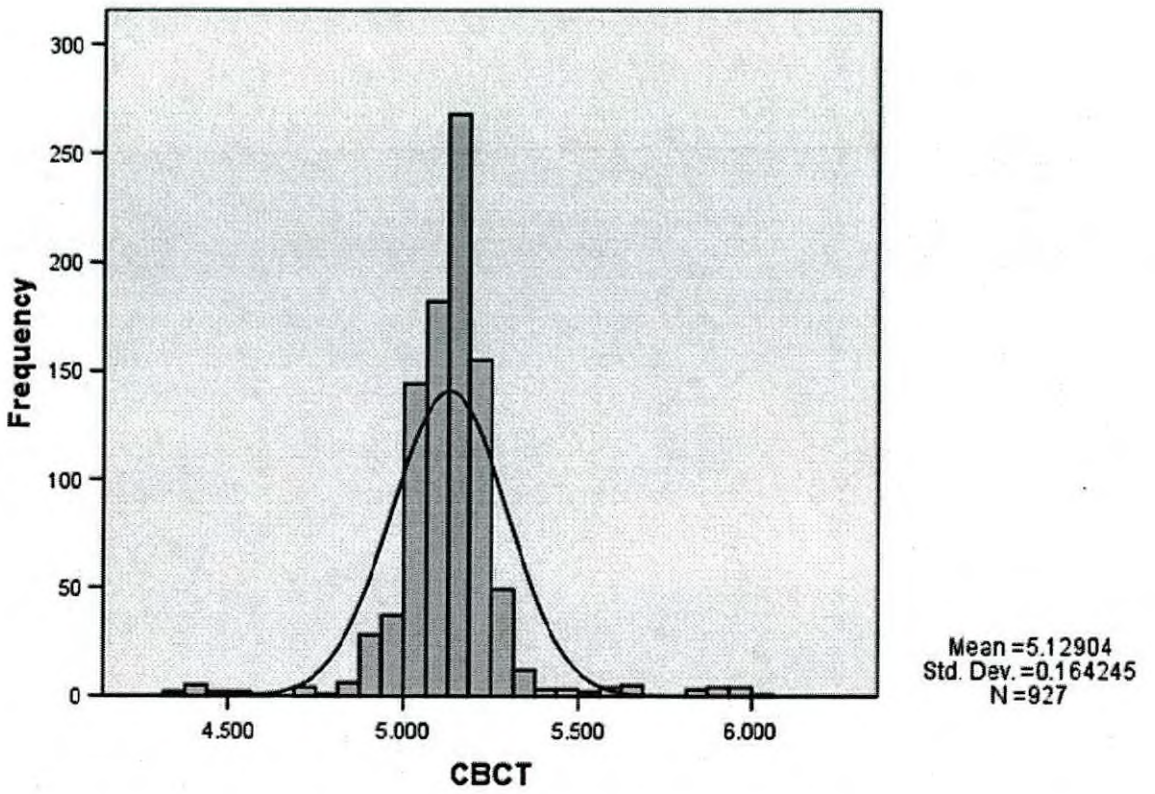


Figure 5. Evaluation of the CBCT measurements for normality. The frequency distribution indicates that the mean absolute differences are normally distributed.

TABLE 48.--Descriptive Statistics for the Direct Measurements

N	Valid	927
	Missing	0
Mean (mm)		5.15835
Median		5.15000
Std. Deviation		0.155848
Variance		0.024
Skewness		1.442
Std. Error of Skewness		0.080
Kurtosis		13.053
Std. Error of Kurtosis		0.160
Range		1.470
Minimum		4.530
Maximum		6.000

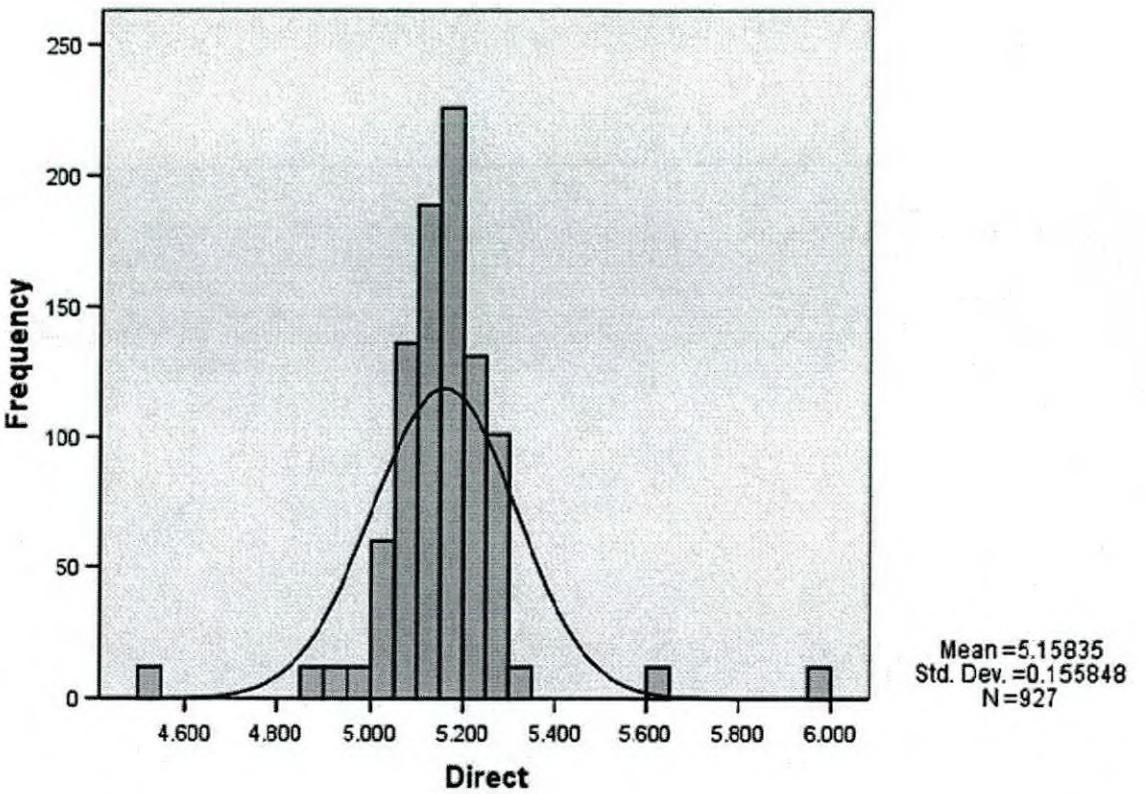


Figure 6. Evaluation of the direct measurements for normality. The frequency distribution illustrates that the direct measurements are normally distributed.

APPENDIX 2

Raw Data: C-Phantom

TABLE 49.--Evaluator Assigned Resolutions for Clear Identification of the Lines in the 6 cm Scans

	6cm 10sec 0.3mm vox		6cm 10sec 0.4mm vox		6cm 20sec 0.4mm vox Denex Mand		6cm 20sec 0.4mm vox Denex Max		6cm 40sec 0.2mm vox Mandibular		6cm 40sec 0.2mm vox Maxillary	
Eval	R1	R2	R1	R2	R1	R2	R1	R2	R1	R2	R1	R2
1	1	1	1	1	1	1	1	1	0.75	0.75	0.75	0.75
2	0.7	0.75	0.75	0.75	0.75	0.75	0.7	0.7	0.65	0.65	0.65	0.7
3	0.75	0.75	0.75	0.75	0.75	0.75	0.7	0.7	0.7	0.7	0.7	0.7
4	1	0.75	0.7	0.75	0.65	0.65	0.7	0.7	0.35	0.35	0.7	0.35
5	0.7	0.75	1	0.75	0.75	1	0.75	1	0.65	0.7	0.7	0.7
6	0.75	0.75	0.75	0.75	0.7	0.75	0.65	0.7	0.7	0.65	0.7	0.7
7	0.65	0.75	0.65	0.75	0.65	0.75	0.7	0.7	0.35	0.75	0.35	0.7
8	0.75	0.75	0.75	0.75	0.75	0.7	0.7	0.75	0.65	0.7	0.75	0.7
9	0.75	0.75	0.75	0.7	0.75	0.75	0.75	0.7	0.35	0.35	0.35	0.35
10	0.75	0.75	0.7	0.7	0.7	0.7	0.7	0.7	0.65	0.7	0.7	0.7
11	0.75	1	1	1	0.7	1	1	1	0.75	0.75	1	0.75
12	0.75	0.75	0.75	0.75	0.7	0.65	0.7	0.75	0.7	0.7	0.7	0.7
13	0.75	1	0.75	1	0.7	0.75	0.75	0.75	0.7	0.7	0.7	0.75
14	0.75	1	0.7	0.75	0.75	0.75	0.75	0.75	0.35	0.35	0.35	0.35
15	0.7	0.75	0.7	0.75	0.7	0.75	0.7	0.7	0.35	0.35	0.35	0.35
16	1	1	1	1	0.75	1	0.75	1	0.75	0.75	0.75	0.75
17	0.75	1	0.75	1	0.75	0.75	0.75	0.75	0.4	0.35	0.35	0.35
18	1	1	1	1	1	1	0.75	1	0.7	0.75	1	0.75
19	0.75	0.75	0.75	0.75	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
20	0.75	1	0.75	1	0.7	0.75	0.7	0.75	0.4	0.35	0.35	0.35
21	0.75	0.75	0.65	0.75	0.75	0.75	0.7	0.75	0.35	0.35	0.35	0.35
22	0.75	0.75	0.7	0.7	0.65	0.65	0.65	0.7	0.65	0.7	0.7	0.7
23	1	1	1	1	1	1	1	1	1	1	1	1
24	0.65	0.65	0.65	0.65	0.6	0.65	0.6	0.6	0.35	0.35	0.35	0.35
25	1	1	1	1	0.7	0.75	0.75	0.75	0.75	0.75	0.75	0.75
26	0.75	0.75	0.75	0.7	0.7	0.7	0.7	0.7	0.35	0.35	0.35	0.35
27	1	1	1	1	1	1	0.75	1	1	1	1	1
28	1	1	1	1	1	1	1	1	0.75	0.75	0.75	0.75
29	1	1	0.75	1	0.7	1	0.75	1	0.7	0.75	0.75	0.75
30	0.75	1	1	1	1	1	1	1	1	0.75	0.75	0.75
Avg	0.838		0.832		0.790		0.785		0.622		0.638	

TABLE 50.--Evaluator Assigned Resolutions for a Clear Identification of Lines in the 8 cm and 13 cm Scans

	8cm 20sec 0.4mm vox		13cm 10sec 0.4mm vox		13cm 20sec 0.3mm vox		13cm 20sec 0.4mm vox		13cm 40sec 0.4mm vox		13cm 40sec 0.25mm vox	
Eval	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2
1	1	1	1	1	1	1	1	1	1	1	1	1
2	0.75	0.75	0.75	0.75	0.75	0.75	0.7	0.7	0.75	0.7	0.7	0.7
3	1	1	0.75	1	0.75	0.75	0.7	0.7	0.7	0.75	0.75	0.75
4	0.75	0.7	0.7	0.75	0.75	0.75	0.7	0.7	0.7	0.7	0.7	0.7
5	0.7	1	0.75	0.75	0.75	1	0.7	1	0.7	1	0.75	0.75
6	0.7	0.7	0.75	0.75	0.75	1	0.75	0.75	0.75	0.75	0.75	0.75
7	0.7	0.75	0.75	0.75	0.75	1	0.7	0.75	0.75	0.75	0.75	0.75
8	0.75	0.7	1	1	1	0.75	0.75	0.75	0.7	0.75	0.75	0.7
9	0.75	0.75	0.75	1	0.7	1	0.7	0.75	0.65	0.75	0.7	0.75
10	0.75	0.75	0.75	0.75	0.75	0.75	0.7	0.7	0.7	0.75	0.75	0.75
11	1	1	1	1	1	1	1	1	0.75	1	1	1
12	0.75	1	1	1	0.75	1	0.7	0.7	0.75	1	0.7	0.75
13	0.75	0.75	1	0.75	0.75	1	0.7	0.7	0.7	0.75	0.75	0.75
14	0.75	1	1	1	0.75	0.75	0.75	1	0.75	1	0.75	0.75
15	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.7	0.7	0.7	0.75
16	1	1	0.75	1	0.75	1	1	1	1	1	0.75	1
17	1	0.75	1	0.75	1	0.75	1	0.7	1	0.7	0.75	0.7
18	1	1	1	1	1	1	1	1	1	1	1	1
19	0.7	0.7	0.75	0.7	0.75	0.75	0.7	0.7	0.7	0.75	0.7	0.7
20	0.75	0.75	0.75	0.75	0.75	0.75	0.7	0.7	0.75	0.7	0.75	0.7
21	0.75	1	0.75	0.75	0.75	0.75	0.75	0.75	0.75	1	0.7	1
22	0.7	0.7	0.75	0.75	0.65	0.7	0.7	0.75	0.7	0.7	0.7	0.7
23	1	1	1	1	1	1	1	1	1	1	1	1
24	0.65	0.65	0.65	0.65	0.6	0.6	0.65	0.65	0.65	0.65	0.65	0.65
25	0.75	0.75	1	1	1	1	0.75	0.75	1	1	0.75	0.75
26	0.7	0.75	0.65	0.75	0.65	0.75	0.7	0.7	0.7	0.7	0.7	0.75
27	1	1	1	1	1	1	1	1	1	1	1	1
28	1	1	1	1	1	1	1	1	1	1	1	1
29	0.75	1	0.75	1	1	0.75	0.75	0.75	0.75	0.75	1	0.75
30	1	1	1	1	1	1	1	1	1	1	1	1
Avg	0.838		0.860		0.848		0.807		0.823		0.804	

TABLE 51.--Evaluator Assigned Resolutions for an Identification of a Pattern of Lines in the 6 cm Scans

	6cm 10sec 0.3mm vox		6cm 10sec 0.4mm vox		6cm 20sec 0.4mm vox Denex Mand		6cm 20sec 0.4mm vox Denex Max		6cm 40sec 0.2mm vox Mandibular		6cm 40sec 0.2mm vox Maxillary	
Eval	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2
1	0.7	0.7	0.65	0.65	0.65	0.65	0.65	0.7	0.35	0.35	0.35	0.35
2	0.65	0.7	0.65	0.65	0.65	0.65	0.7	0.65	0.35	0.35	0.35	0.35
3	0.7	0.7	0.7	0.7	0.65	0.7	0.7	0.7	0.35	0.35	0.35	0.35
4	0.7	0.7	0.65	0.65	0.6	0.65	0.65	0.65	0.35	0.35	0.35	0.35
5	0.65	0.65	0.65	0.65	0.65	0.7	0.65	0.7	0.35	0.4	0.35	0.35
6	0.65	0.7	0.65	0.7	0.65	0.65	0.65	0.65	0.35	0.35	0.35	0.35
7	0.65	0.7	0.65	0.65	0.65	0.65	0.65	0.65	0.35	0.35	0.35	0.35
8	0.6	0.6	0.6	0.6	0.65	0.6	0.6	0.6	0.4	0.35	0.45	0.4
9	0.65	0.7	0.65	0.65	0.7	0.65	0.65	0.65	0.35	0.35	0.35	0.35
10	0.65	0.75	0.65	0.65	0.65	0.65	0.65	0.7	0.65	0.65	0.7	0.65
11	0.7	0.7	0.65	0.7	0.65	0.65	0.65	0.7	0.65	0.65	0.7	0.7
12	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.35	0.35	0.35	0.35
13	0.65	0.7	0.65	0.65	0.65	0.7	0.35	0.65	0.35	0.35	0.7	0.35
14	0.65	0.7	0.65	0.7	0.65	0.65	0.65	0.65	0.35	0.35	0.35	0.35
15	0.65	0.7	0.6	0.65	0.6	0.65	0.6	0.65	0.35	0.35	0.35	0.35
16	0.65	0.7	0.65	0.75	0.7	0.7	0.65	0.7	0.4	0.35	0.35	0.35
17	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.7	0.35	0.35	0.35	0.35
18	0.75	0.75	0.75	0.75	0.7	0.75	0.7	0.75	0.7	0.7	0.75	0.7
19	0.7	0.7	0.65	0.7	0.65	0.65	0.65	0.65	0.35	0.35	0.35	0.35
20	0.7	0.75	0.65	0.65	0.65	0.65	0.65	0.65	0.35	0.35	0.35	0.35
21	0.6	0.65	0.6	0.7	0.6	0.65	0.6	0.65	0.35	0.35	0.35	0.35
22	0.65	0.7	0.65	0.65	0.6	0.65	0.6	0.65	0.4	0.35	0.35	0.35
23	0.65	0.75	0.7	0.75	0.65	0.75	0.7	0.7	0.35	0.35	0.35	0.35
24	0.6	0.65	0.6	0.6	0.55	0.6	0.55	0.55	0.35	0.35	0.35	0.35
25	0.7	0.65	0.65	0.7	0.65	0.65	0.7	0.7	0.35	0.35	0.35	0.35
26	0.7	0.65	0.7	0.65	0.65	0.65	0.65	0.65	0.35	0.35	0.35	0.35
27	0.7	0.75	0.75	0.75	0.7	0.75	0.7	0.7	0.7	0.7	0.7	0.7
28	0.75	0.75	0.75	0.7	0.75	0.7	0.7	0.7	0.35	0.35	0.35	0.35
29	0.75	0.75	0.7	0.75	0.65	0.75	0.7	0.7	0.4	0.4	0.35	0.35
30	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.7	0.35	0.35	0.35	0.35
Avg	0.683		0.668		0.659		0.657		0.398		0.405	

TABLE 52.--Evaluator Assigned Resolutions for an Identification of a Pattern of Lines in the 8 cm and 13 cm Scans

	8cm 20sec 0.4mm vox		13cm 10sec 0.4mm vox		13cm 20sec 0.3mm vox		13cm 20sec 0.4mm vox		13cm 40sec 0.4mm vox		13cm 40sec 0.25mm vox	
Eval	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2
1	0.65	0.7	0.7	0.7	0.75	0.75	0.7	0.7	0.7	0.7	0.65	0.65
2	0.65	0.65	0.7	0.7	0.55	0.55	0.65	0.65	0.65	0.65	0.65	0.65
3	0.65	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.65	0.65
4	0.7	0.7	0.7	0.7	0.65	0.75	0.7	0.7	0.65	0.7	0.65	0.65
5	0.65	0.65	0.7	0.75	0.75	0.75	0.7	0.7	0.7	0.7	0.65	0.7
6	0.65	0.65	0.65	0.75	0.7	0.7	0.75	0.7	0.7	0.7	0.65	0.7
7	0.65	0.65	0.7	0.7	0.65	0.75	0.7	0.7	0.65	0.65	0.65	0.65
8	0.6	0.45	0.6	0.55	0.65	0.6	0.6	0.6	0.55	0.6	0.6	0.55
9	0.65	0.7	0.7	0.75	0.7	0.75	0.7	0.7	0.65	0.7	0.65	0.7
10	0.7	0.7	0.65	0.7	0.7	0.65	0.7	0.65	0.6	0.65	0.7	0.7
11	0.7	0.7	0.75	0.7	1	0.75	0.7	0.7	0.7	0.65	0.65	0.65
12	0.65	0.65	0.7	0.7	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65
13	0.65	0.7	0.75	0.75	0.7	0.7	0.65	0.65	0.65	0.65	0.7	0.7
14	0.7	0.7	0.75	0.75	0.7	0.65	0.7	0.7	0.7	0.7	0.7	0.55
15	0.65	0.7	0.65	0.7	0.7	0.65	0.7	0.7	0.65	0.7	0.65	0.65
16	0.7	0.7	0.7	0.75	0.7	0.75	0.65	0.75	0.65	0.7	0.7	0.7
17	0.7	0.7	0.7	0.7	0.65	0.7	0.7	0.7	0.65	0.65	0.65	0.65
18	1	0.75	0.75	1	1	0.75	1	1	0.75	0.75	0.75	1
19	0.65	0.65	0.7	0.7	0.7	0.7	0.7	0.7	0.65	0.7	0.65	0.65
20	0.65	0.7	0.65	0.7	0.7	0.55	0.7	0.65	0.65	0.65	0.65	0.6
21	0.65	0.7	0.65	0.65	0.55	0.7	0.65	0.7	0.7	0.7	0.65	0.7
22	0.65	0.65	0.65	0.7	0.65	0.65	0.65	0.7	0.65	0.65	0.65	0.65
23	0.7	0.7	0.75	0.75	0.75	0.75	0.7	0.7	0.7	0.7	0.7	0.7
24	0.6	0.6	0.6	0.6	0.55	0.55	0.6	0.6	0.6	0.6	0.65	0.55
25	0.7	0.65	0.7	0.7	0.65	0.65	0.7	0.7	0.65	0.7	0.65	0.65
26	0.65	0.65	0.65	0.6	0.65	0.65	0.6	0.6	0.65	0.65	0.55	0.55
27	0.7	0.75	0.75	0.75	0.75	0.75	0.75	0.7	0.75	0.75	0.7	0.75
28	0.7	0.7	0.75	0.75	0.75	0.75	0.7	0.7	0.7	0.7	0.7	0.7
29	0.7	0.7	0.75	0.75	0.75	0.75	0.7	0.7	0.7	0.7	0.75	0.7
30	0.65	0.65	0.7	0.7	0.7	0.75	0.7	0.7	0.65	0.65	0.65	0.7
Avg	0.676		0.704		0.697		0.693		0.673		0.666	

Instructions for Looking at the Images:

1. The participation in this study is entirely voluntary and is designed to utilize young volunteers with near ideal eyesight (naturally or corrected) to evaluate images on a computer screen. You are free to resign from the study at any time without penalty. No personal information will be collected and your name is not to be written on any documents. Your participation is strictly confidential and will be known only by the conducting researcher, John Ballrick.

2. If you choose to participate, you will be shown a PowerPoint presentation with a series of images. The images are labeled #1 through #24 and will correspond to a collection form that you will receive from the researcher.

3. All of the images are labeled A through I. Please look at each of the lettered choices to answer the following questions (please read the instructions carefully and look at each of the lettered choices for each image number!):

    a. Which lettered choices (you can choose more than one letter) show a clear, distinct separation between the four white vertical lines?
    b. Which lettered choices (you can choose more than one letter) allow an identification of a pattern of four lines (it does not necessarily have to be a clear delineation of the lines)?

4. Please circle the corresponding letter for each image on the collection sheet. If you feel that none of the lettered selections conforms to the criteria above, then you should circle the selection X.

5. When you have completed the evaluation of the 24 images, please hand your collection form to the conducting researcher, John Ballrick.

6. Thank you for your participation!

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