Evaluation of Radiographic Orthodontic Records Image Quality

Derived from CBCT

BY

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THESIS

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This thesis is dedicated to my loving and devoted husband Lakhwinder Singh whose unconditional love and commitment gives me the strength to persevere and whose passion for life inspires me every day. This is also dedicated to my father and mother who inspire me to do better in every aspect of my life.
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<table>
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<th>Abbreviation</th>
<th>Description</th>
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<tr>
<td>AAO</td>
<td>American Association Of Orthodontists</td>
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<tr>
<td>ASD-POCS</td>
<td>Adaptive-Steepest-Descent-Projection-Onto-Convex-Sets</td>
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<td>CBCT</td>
<td>Cone Beam Computed Tomography</td>
</tr>
<tr>
<td>CT</td>
<td>Computed Tomography</td>
</tr>
<tr>
<td>DICOM</td>
<td>Digital Imaging And Communications In Medicine (DICOM) (National Electric Manufacturers Association, Rosslyn, VA)</td>
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<tr>
<td>E</td>
<td>Effective Dose</td>
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<tr>
<td>FDA</td>
<td>Food And Drug Administration</td>
</tr>
<tr>
<td>FDK</td>
<td>Feldkamp, Davis And Kress Algorithm</td>
</tr>
<tr>
<td>Gy</td>
<td>Gray (Measurement Of Absorbed Dose)</td>
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<tr>
<td>ICRP</td>
<td>International Commission On Radiological Protection</td>
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<tr>
<td>LC</td>
<td>Lateral Cephalogram</td>
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<tr>
<td>Micro-CT</td>
<td>Micro Computed Tomography</td>
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<td>PA CEPH</td>
<td>Posterior Anterior Cephalogram</td>
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<tr>
<td>PANO</td>
<td>Panoramic Radiograph</td>
</tr>
<tr>
<td>SI</td>
<td>International System Of Units</td>
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<tr>
<td>TACT</td>
<td>Tuned-Aperture Computed Tomography</td>
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<tr>
<td>μSv</td>
<td>Micro-Sieverts (Measurement Of Effective Dose)</td>
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<tr>
<td>2D</td>
<td>Two-Dimensional</td>
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<tr>
<td>3D</td>
<td>Three-Dimensional</td>
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SUMMARY

A study was performed to determine the use of a specific reconstruction algorithm (RA), adaptive-steepest-descent-projection-onto-convex-sets (ASD-POCS) on the image quality of orthodontic radiographic images constructed from cone beam computed tomography (CBCT). CBCT scans of two patients were obtained retrospectively from i-CAT Next Generation (Imaging Sciences, Hatfield, PA) CBCT scanner, College of Dentistry, University of Illinois at Chicago.

A specific RA was used for sparse image reconstruction using the raw data obtained from two CBCT scans. Four different image reconstructions were prepared using ASD-POCS. Reconstructed images varied among each other in the number of basis images. These were RA 300, same as the i-CAT image (control) and reducing the number of basis images to RA 150, RA 79, and RA 33. All the CBCT images with different numbers of basis images were used to reconstruct the multiplanar images of the panoramic view, lateral cephalogram, and posterior-anterior cephalogram manually using Dolphin 3D software (v. 11.7, Chatsworth, CA).

Seventy three examiners evaluated the reconstructed 2D radiographs (panoramic, lateral, and posterior-anterior cephalogram) for the purpose of general screening, diagnosis, and treatment planning from the reconstructed CBCT images. The examiners were orthodontists, orthodontic residents, oral surgeons, oral surgery residents and oral and maxillofacial radiologists.

Using the preferences (Yes/No) and 10 point rating scale the examiners evaluated if the images were diagnostic for screening, diagnosis, and treatment planning by identification of specified landmarks. Non-parametric tests were used to determine statistical significant differences among the reconstruction views of each radiograph type. If differences existed, sparse view reconstruction pairs were compared to determine the statistical significance among them.
SUMMARY (continued)

Preferences for all the images were statistically significant (p<0.05). Mostly, for all 2D reconstructed images, RA 300 was preferred over i-CAT (control) and had the highest mean rank. For the panoramic view, it was found that the quality of the images with the full number of basis images RA 300 and RA 150 were not significantly different from the i-CAT reconstructed images. For the lateral cephalogram, it was found that the images generated from RA 300, RA 150, and RA 79 number of basis images were not significantly different, resulting in usable images with up to one half and one fourth reduction in number of projections. For the posterior-anterior cephalogram, the quality of the images reconstructed from RA 300 and RA 150 were not significantly different. This shows that reconstruction algorithm ASD-POCS could be used to reduce the number of basis images while maintaining the image quality for the purpose of orthodontic records (panoramic view, lateral and posterior-anterior cephalogram).
1. INTRODUCTION

1.1 Background

Orthodontic imaging plays an important role in diagnosis, treatment planning, and assessment of the quality of the results of orthodontic treatment. Imaging technology has changed over time along with the other advances in the field of orthodontics. Radiographic imaging may include using two-dimensional (2D) (conventional and digital radiography) and three-dimensional techniques (3D) (Cone-beam Computed Tomography).

X-rays were first discovered in 1885. In 1931 the first cephalometer was introduced by Broadbent in the United States and Hofrath in Germany. The lateral cephalogram enabled orthodontists to see the positions of jaws and teeth and enabled them to examine how jaw relation discrepancies could lead to a malocclusion. Use of radiographic cephalograms also led to a wealth of information from growth studies and the evaluations of treatment outcomes. Practitioners have been using 2D imaging techniques such as the panoramic radiograph, lateral cephalogram, posterior-anterior cephalogram, hand wrist radiograph, and full mouth series. The limitations of two-dimensional analyses include image magnification, geometric distortion, and superimposition of structures. Despite the limitations of two-dimensional radiography, practitioners are not discouraged from using the technology because the limitations of 2D radiographs are clinically insignificant and do not affect the results of treatment.

Imaging was limited to two-dimensional until Rosenberg (1967) first used conventional tomography (CT) on the maxillofacial region. The limitations of this technique were the superimposition of the out of focus structures, the time consuming process and the high radiation
dose. Once a patient left the clinic after the ionization exposure, no additional data could be produced.

CT emerged as a 3D diagnostic tool in dentistry for the assessment of oral and maxillofacial pathologies, trauma, and for implants. The limitations of this modality are the longer scan time, radiation dose, and expensive equipment. (Scribano et al., 2003), (Scarfe and Farman, 2008)

In 1997, tuned-aperture computed tomography (TACT) was invented as a 3D diagnostic tool for the maxillofacial region. The TACT algorithm was tested using a multi-tube tomosynthetic system producing in vitro projections of a tooth with a carious lesion (Webber et al., 1997). This technique was laborious with extensive imaging equipment and also involved more radiation exposure then 2D imaging.

Cone beam computed tomography (CBCT) is a three dimensional modality that provides volumetric data. The first maxillofacial commercially available CBCT was NewTom 9000 (Quantitative Radiology, Verona, Italy) in Europe in the 1990s. The United States Food and Drug Administration (FDA) approved it in 2001. There are 40 CBCT systems available on the market (Horner et al., 2013), (Scarfe and Farman, 2008).

CBCT has become a substitute for medical CT for a majority of cases in the maxillofacial area because of the lower radiation dose, relatively low cost of equipment, and shorter scan time. It has clinical applications in situations when 2D radiographs are not sufficient for diagnosis and treatment planning in dentistry.

The routine use of CBCT in orthodontics is an area of debate. It has been discussed in the point and counterpoint section of the American Journal of Orthodontics and Dentofacial
Orthopedics (AJODO) (Larson, 2012) (Halazonetis, 2012). One of the concerns with the routine use of CBCT use is the effect of ionizing radiation on growing children. The CBCT industry has improved on this technology over two decades of its use in dentistry. With technologic advances such as the use of flat panel detectors, the availability of different fields of view, and the advances in computer science great contributions have been made towards the reduction of radiation exposure by CBCT technology.

In the field of medical radiology, reconstructed algorithms (RA) have been applied to CBCT scans (Qiu et al., 2013). The low-dose CBCT reconstruction algorithm using the barzilai-borwein step-size calculation cuts the radiation dose while maintaining the image quality (Park et al., 2012). These algorithms have not yet been applied to CBCTs used for reducing radiation exposure in orthodontic records.

1.2 **Specific Aims**

The purpose of the study is to assess and to find acceptable level of the image quality of orthodontic records (panoramic radiograph, lateral and posterior-anterior cephalograms) derived from CBCT reconstructed images using different level of sparse-view image reconstruction with the novel adaptive-steepest-descent-projection-onto-convex-sets (ASD-POCS) algorithm.

1.3 **Significance of the Study**

CBCT gives dental practitioners a third dimension in the diagnosis and treatment planning when compared to 2D radiographs. Some clinicians in their search for average and normative 3D data of the craniofacial complex have adopted 3D CBCT imaging as a routine diagnostic tool regardless of the complexity of the case. In some instances, unfortunately, 3D imaging data have
been gathered from patients with simple dental problems and normal craniofacial structures. Dosimetry studies have shown that the radiation exposure varies based on the machine, the exposure parameters and the field of view. The radiation risks from CBCT have been a focus recently due to several recent publications on radiation risk in children and the short and long term effects of ionizing radiation (AAOMR, 2013).

There are no indications outlined in the literature for acquiring a CBCT scan. It is recommended to acquire the scan when traditional radiographs are not adequate for a clinical diagnosis. The American Association of Orthodontists (AAO) delivered a statement in 2010, “that while there may be clinical situations where a CBCT may be of value, the use of such technology is not routinely required for orthodontic radiography” (American Association of Orthodontists Resolution 26-10H, 2010).

There are a number of methods suggested by different studies to reduce the radiation exposure of the patient. Choosing the field of view according to the diagnostic task and changing the settings on the machine according to the age of the patient are some modifications suggested in the operating instructions of the machine, however not all the machines on the market have the ability to change the settings.

Use of reconstruction algorithms has not been reported in the dental literature. It has been used in medical literature, e.g. in micro-computed tomography (MicroCT). MicroCT is a biomedical research tool that uses x-rays to create a three dimensional object of very high resolution. For small samples, MicroCT acquires 300-1000 basis images per sample. High radiation can degrade the sample, so an iterative reconstruction algorithm ASD-POCS has been shown to reduce the number of basis images needed to construct 3D images while maintaining
their image quality. It has been shown to reduce the amount of radiation exposure by 67% (Xiao et al., 2011). Specific to the field of orthodontics, once an algorithm has been established to find the minimal number of 2D projections required to fully reconstruct 3D data, a low dose scan can be used to produce clinically useful images suitable for an orthodontic diagnosis hence reducing ionization radiation exposure to the patient.

1.4 **Null Hypothesis**

No mean difference exists in orthodontic diagnostic image quality for each image type (lateral cephalogram, posterior-anterior cephalogram and panoramic radiograph) derived from different level of sparse-view cone beam computed tomography images using the ASD-POCS algorithm.
2. REVIEW OF THE LITERATURE

2.1 Growth of Imaging in Dentistry:

The discovery of x-rays has revolutionized medical diagnostics. Wilhelm Conrad Rontgen discovered x-rays in 1895. After the invention of x-rays, the first dental radiograph was made by Fredrich Otto Walkhoff of Braunschweig, Germany in 1896.

George Eastman followed the discovery of the dental radiograph and introduced the analog film (silver halide film) to the specialty of dentistry. Dentists have been using the Kodak analog x-ray films ever since. In 1986, Francis Mouyen filed a patent in the United States for the first intraoral digital sensor exposure of charge coupled device (Zeller, 2013). Even after 25 years of digital radiography, only 30% of US dentists are using it instead of conventional radiography (Brian and Williamson, 2007). Medical CT was developed in 1967 and its first use in clinical studies was by Godfrey Hounsfield in 1972. There have been technological advancements in CT technology ever since, mainly in the detector system and the data acquisition systems. Most recent CT scanners use a fan beam of radiation for the exposure.

Radiographic imaging has been an important tool in orthodontics for diagnosis, treatment planning, and assessing the quality of results of the treatment. Imaging may include 2D and 3D techniques. The most common 2D imaging techniques used in orthodontics are the panoramic radiograph, lateral cephalogram, posterior-anterior cephalogram, hand wrist radiograph, and full mouth series. Practitioners have been using 2D imaging for decades with good treatment results. The limitations of 2D analyses include image magnification, geometric distortion, and superimposition of structures. The clinical use of CBCT has evolved in the United States and many
orthodontists have accepted this new imaging modality because of its uses in diagnosis, treatment planning, and progress assessment during treatment.

CBCT was used in medical diagnostics before its use in the maxillofacial area. The first CBCT scanner was built at the Mayo Clinic in 1982 (Robb, 1982). It has also been used for radiation therapy planning and mammography. The first maxillofacial CBCT was designed by Quantitative Radiology (Verona) in Italy in 1995. This product was patented by Atillo Tacconi and Piero Mozzo. In the United States, the first maxillofacial CBCT device, the New Tom 9000 (QR, Verona, Italy) was approved in 2001. The adoption of CBCT technology in dentistry has expanded exponentially because of numerous technical improvements and commercial market forces.

Many CBCT devices are now multimodal, providing panoramic and cephalometric imaging either directly similar to traditional panoramic machines or indirectly from reconstruction from their 3D data set. Most of them are suitable for dental office placement. The machines are technically as easy to operate as panoramic units, allow collimation of the beam to the region of interest to reduce patient radiation exposure, and produce high quality images of optimized resolution.

Dental practitioner referral was studied by Arnheiter et al., (2006) in their study of trends in maxillofacial CBCT technology. They reported that most referrals were from oral and maxillofacial surgeons (51%) and periodontists (17%). A recent survey conducted by Smith et al., (2011) showed that 36 out of 69 orthodontic programs across Canada and the United States have access to CBCT. Four programs use CBCT as a diagnostic tool on all patients. A radiologist was responsible for interpretation of CBCT results in 59% of the programs, while in 32% residents
were responsible reading and referring for any abnormal findings for further evaluation. Mostly CBCT was used in the programs for specific diagnostic purposes. The use of CBCT is increasing exponentially.

In 2010, The New York Times published an article on radiation worries and explained to the public how some dentists and orthodontists are luring their patients in with the use of 3D images. The average annual radiation dose from background radiation is 2.4mSv/y (2400 µSv) (Henri and Mario 2006). The annual radiation dose perspective is useful for establishing an average radiation dose but it varies greatly geographically. With the increasing awareness of the effects of radiation on human health, any medical or dental exposure of ionizing radiation is put into perspective. Lately this topic has been receiving much attention from the public.

In orthodontics, CBCT is a valuable tool and has been used for locating supernumerary or impacted teeth, determining the thickness and morphology of bone at the sites of mini-implants, and for planning orthognathic surgical cases. It could also be used to create 3D virtual models which could be used as registration points for 3D superimposition.

2.2 CBCT Scanners

CT scanners have an x-ray generating source and a detector mounted on a framework that revolves around the object. A fan shaped x-ray beam is used and the image data is captured by the detector. The images can be reconstructed from the stacks of axial slices. Recent medical CT scanners have a linear arrangement of multiple detectors that can capture more slices simultaneously to reduce the scan time (Scarfe and Farman, 2008).

CBCT imaging is performed using a revolving platform to which the x-ray source and detector are fixed similar to a traditional panoramic machine. The x-ray source and detector rotate
around the object being scanned. A sequential set of images are acquired in an arc of 180° or 360° and are mathematically reconstructed into a volumetric dataset. Only one rotation is needed to acquire enough data. The radiation exposure can be pulsed or continuous. With one rotation of the cone shaped x-ray beam and detector around the region of interest, 2D images are captured by the detector. These 2D images are called basis images. Depending on the field of view (FOV), about 150 to more than 600 basis images could be acquired (Scarfe and Farman, 2008)

CBCT scanners differ from each other in the x-ray detector system. Different types of image detectors include an image intensifier tube, a charge coupled device, or a flat panel detector. Images taken with the image intensifier tube include more noise than the flat panel detector images (Baba et al., 2002; Baba et al., 2004). The flat panel detector absorbs the x-ray photons and sends an electric charge to the computer. One advantage of flat panel detectors or solid state detectors is improved photon utilization. Image intensifiers capture photons and convert them into electrons that interact with a fluorescent screen. The screen then emits light which is captured by a charge-coupled device camera (Howerton and Mora, 2008).

After the exposure of the patient with the cone shaped x-ray beam, a computer captures the information from either the solid state detector or the image intensifier. A manufacturer provided software reconstructs the projection data via an algorithm into reconstructed images. In CBCT, 3D volume is reconstructed from 2D data using cone-beam reconstruction. The Feldkamp, Davis, and Kress (FDK) algorithm is the most popular algorithm used for CBCT reconstruction (Feldkamp et al., 1984). This image data is stored in Digital Imaging and Communications in Medicine (DICOM) (National Electric Manufacturers Association, Rosslyn, VA) data format. The DICOM data is then imported into a viewing software for analysis.
CBCT has been shown to be better than multidetector CT because of its collimated x-ray beam, rapid scan time, inexpensive equipment, lesser radiation dose, and better image accuracy (Scarfe and Farman, 2008).

2.3 CBCT Data Acquisition

CBCT data acquisition differs from CT in that the x-ray source generates a cone beam of radiation. The 2D detectors are attached to the tube by an arm so both the tube and the detectors rotate around the stationary object by either 180° or 360°. The cone beam focuses the radiation on the object to reduce the scatter and thereby reduce the radiation (Scarfe and Farman, 2008). Recent modifications in the data acquisition include fusing the scans to increase the FOV of the object. Beam projection geometry and the detector size determine the FOV of the machine.

Radiation exposure of an object can be pulsed or continuous. Each exposure produces 2D projections known as frame or basis images. Frame rate is the number of projections acquired per second. The number of frames comprising the projection data varies depending on the frame rate and the time of the radiation exposure. According to Farman et al. (2006), “the higher the frame rate, the more information that is available to construct the image; however, the signal-to-noise ratio of individual slices is also decreased.”

Different machines have different exposure cycles and different number of frames for data acquisition. X-ray beams can be collimated to produce a smaller FOV with a smaller scan time. FOV should be chosen by the practitioner per each individual patient’s needs.

The following are the different FOV available according to the scan volume height in the machines (Scarfe and Farman, 2008):
• Localized-5 cm or less (Dentoalveolar and TMJ)
• Single arch-5 cm to 7 cm (Maxilla or mandible)
• Interarch-7 cm to 10 cm (Mandible and superiorly to include inferior nasal concha)
• Maxillofacial-10 cm to 15 cm (Inferior border of the mandible to nasion)
• Craniofacial-Greater than 15 cm (Inferior border of the mandible to vertex)

2.4 Image Characteristics

Digital images are constituted by pixels, the smallest unit of the two-dimensional grid composing the image. Each pixel has its own color, size, intensity value, and position in an image. Image resolution and sharpness depend on the number of pixels/length of the image (pixels/mm) and the number of grays per pixel (bits).

The smallest detecting unit in a CBCT is a voxel, which is a three dimensional block of cuboid structure. A voxel in three dimensional imaging is comparable to a pixel in two dimensional imaging. The voxel also represents the specific degree of x-ray absorption. Voxel size determines the image resolution. The smaller the voxel size, the better the resolution.

CBCT voxels are sized in sub-millimetric resolution at 0.125\text{mm} to 4\text{mm} (Scarfe et al., 2006). The feature of 1:1 image production is used for accurate implant treatment planning and fabrication of stereolithographic guides to assist in implant placement (Hatcher et al., 2003) (Sarment et al., 2003). Because of the isotropic voxel size in CBCT and anisotropic voxels in the medical CT, CBCT has the same resolution in the horizontal plane and better resolution in vertical plane.
2.5  Image Display

CBCT scanners originally provide projection data. Secondary reconstructions as axial, coronal, and sagittal orthogonal views are created using software. Proprietary software is capable of importing the DICOM data and reconstructing various images necessary for diagnosis and treatment planning. Three techniques can be used for this process: oblique planar reformation, curved planar reformation, and multiplanar volume reformation.

The oblique reformation technique creates 2D images similar to traditional 2D cephalograms. The image is constructed by a cut across a stack of axial images. This is used for evaluating specific structures such as any pathology or TMJ. The curved reformation technique consists of reformatting an image by aligning the long axis of the imaging plane with an anatomic structure similar to the construction of a panoramic image using the dental trough.

The multiplanar volume reformation increases the volume of the image so the thickness of the image can be increased by adding adjacent voxels in the slice. This produces a ray sum image. This method can be used to increase the thickness of any oblique or curved reformation such as the panoramic image and the lateral cephalogram (Scarfe et al., 2006).

2.6  Image Quality

Image quality in traditional radiography is defined as "the ability to record each object as a point on a film" (Curry, 1990). The image is a replication of the anatomical information caught by the x-ray equipment and the quality of an image is assessed by the judgment of an examiner. There are two approaches, explained by Martin et al. (1999), to describe the subjective assessment of imaging. The first is suitable when a question requires a binary response. This approach is used for testing the specificity or sensitivity of the quality. One of the major drawbacks with this
approach is that subject knows the answer because the question is formatted as true/false. The other drawback is that this approach cannot be used for borderline cases. The second method is to evaluate the relative measures of the quality by asking the observer to rank the images with his/her preference. One of the strengths of this approach is that by repeating the exercise with multiple images or among different observers, their agreement will be an indicator of superiority qualitatively. The drawback to these approaches is that they are qualitative analyses.

There are a number of studies performed on CT evaluating the image quality after changing the kVp or mA values. Sohaib et al. (2001) has shown that reducing the mA value from 200 mA to 50 mA in paranasal sinus CTs retains the diagnostic quality of the film.

Image quality has been evaluated on CBCT images by using different settings on the machines. Kwong et al. (2008) evaluated the quality of CBCT scans with different kVp, mA, and presence or absence of copper filters. CBCT scans were acquired using a fresh cadaver head and a skull using a CB MercuRay (Hitachi Medical Systems, Tokyo, Japan) scanner. Three different FOV’s (6”, 9” and 12”) were used. Images were captured by changing the machine voltage and the current (Kvp and mA). 48 images were captured. The manufacturer’s software was used to reconstruct and segment the images. All the images were printed on high quality paper and were shown to 30 judges (faculty and residents of Case Western Reserve University, Cleveland, OH). The quality of the images was assessed on a scale. Their conclusions were that neither the presence nor absence of a filter, nor changing the tube voltage affected the quality of the images. However, changing the tube current (mA) to a lower setting in different FOV showed images with good diagnostic quality.
Lofthag-Hansen et al. (2011) evaluated the image quality of CBCT images for implant planning and periapical diagnosis on three different FOV images. This study was conducted using 3D Accuitomo (FOV 3 cm x 4 cm) and 3D Accuitomo FPD (FOVs 4 cm x 4 cm and 6 cm x 6 cm). The posterior part of maxilla and the mandible of a skull phantom was imaged using 60, 65, 70, 75 and 80 kV and 2, 4, 6, 8 and 10 mA with rotation of 180° and 360°. These images were presented to seven observers with experience to assess the CBCT image quality on calibrated computers. Their finding was that the exposure parameters could be changed for a specific FOV for a specific task. Image quality studies on CBCT by Kwong et al. (2008) and Lofthag-Hansen et al. (2011) showed that exposure parameters could be changed for a specific diagnosis on a specific image.

Image quality studies have been performed comparing different algorithms. The ability of the ASD-POCS algorithm has been compared with existing algorithms like the Feldkamp-Davis-Kress (FDK). ASD-POCS can generate images of the same quality as FDK using one sixth of the original radiation dose (Xiao et al., 2011).

Image quality and radiation dose are two related clinical issues. Every clinical situation has different expectations from the quality of the image. To generate a good quality image, the signal to noise ratio is higher and images are of higher resolution but the radiation dose is higher, thus increasing the radiation risk.

2.7 CBCT Applications

A systematic review on CBCT was conducted by De Vos et al. (2009). One hundred seventy seven papers were studied and Eighty six papers were associated with the clinical applications. Twenty five papers were on pathologies in the maxillofacial area and most of the papers were on locating supernumerary teeth. Thirty five papers elucidated the use of CBCT in
maxillofacial surgery. Fourteen papers were on CBCT’s use in orthodontics and eleven were on treatment planning cases for implants. Based on the review, CBCT’s clinical applications for orthodontics are:

- **Miniscrews**
  - Assessing the bone thickness (Gracco et al., 2006)
  - Safe zones for their placement (Poggio et al., 2006)
  - Fabrication of a surgical splint (Kim et al., 2007)
- **Cephalometry** (Botticelli et al., 2011; Farman and Scarfe 2006)
- **Assessment of RPE** (Rungcharassaeng et al., 2007)
- **Boundaries of orthodontic tooth movement** (Kapila et al., 2011)
- **Impacted teeth** (Botticelli et al., 2011)
- **Pathology** (Cha et al., 2007)
- **Treatment planning** (Schmuth et al., 1992, Ericson and Kurol, 2000)

Other than orthodontics, another major area for the use of CBCT in dentistry is in treatment planning for implant placement (Baba et al., 2002; Baba et al., 2004; Scarfe et al., 2006; Hatcher et al., 2003; Sarment et al., 2003). In the medical literature, CBCT has been used for image guided radiation therapy (IGRT); to target the treatment position in a radiation therapy patient. CBCT improves the accuracy of the final delivery of the treatment to the affected region for radiation therapy. There are however, multiple radiation exposures during a treatment course (Wang et al., 2009).
2.8 **CBCT Radiation Risk**

CBCT has played a great role in clinical diagnosis but one of the biggest concerns with its use is the exposure to ionizing radiation. Ionizing radiation can be measured using absorbed dose, equivalent dose, and effective dose. Absorbed dose is the x-ray energy absorbed by a unit of mass of tissue. The International System of Units (SI) unit for absorbed dose is the Gray. The biologic effect of different types of radiation on tissue or organs is assessed by equivalent dose. The SI unit for equivalent dose is the Sievert (Sv). For the estimation of radiation dose on human beings, effective dose is measured (Li, 2013).

According to De Vos et al. (2009), the radiation dose of CBCT scanners should be reported in effective dose (E) which should be measured in milli-sieverts (mSv) or micro-sieverts (µSv). E has also been reported by the International Commission on Radiological Protection (ICRP) “as a means of comparing damage of different exposures of ionization radiation to an equivalent detriment by full body dose of radiation.”

- \[ E = \sum W_T H_T \]
  - E is the effective radiation dose
  - \( W_T \) is tissue weighing factor
  - \( H_T \) is the equivalent dose
    - The product of radiation weighing factor and absorbed dose averaged over particular tissue or organ.
  - \[ H_T = \sum W_R D_T \]
    - \( W_R \) is the radiation weighing factor
    - \( D_T \) is the absorbed dose. The unit of the absorbed dose is milligray (mGy).
The ICRP reported two different versions of tissue weighing factors in 1990 & 2005. In the literature, authors have reported the effective doses using different measurements and different tissue weighing factors from different years of recommended tissue weighing factors (Cohnen et al., 2002). The most recent ICRP 2005 recommendations have taken the salivary glands into account so effective doses are higher than ICRP 1990 recommendations (Ludlow et al., 2006).

Ludlow has conducted a number of studies on this matter. Ludlow et al. (2003) compared the CBCT radiation doses of NewTom 9000 and Orthopos plus DS panoramic unit. The effective dose of the CBCT scanner was reported as 36.9 µSv and the panoramic dose was 6.2 µSv. Digital cephalogram’s effective dose E per ICRP 1990 recommendation was reported as 3.2 µSv.

Ludlow et al., (2006) measured the effective doses of three different CBCT scanners; NewTom 3G, CB Mercuray, and i-CAT. Effective radiation doses were reported separately per ICRP 1990 & 2005 recommended tissue weighing factors. The FOV for the three scanners was 12”. RANDO Phantom & TLD sensors were used. Machine parameters were used as recommended by the manufacturer. Their conclusions were 12” FOV effective doses in micro-sieverts (µSv) were 45-59 (NewTom3G), 135-193 (i-CAT), and 477-558 (CB Mercuray) per ICRP 1990 and ICRP 2005 recommendation. NewTom 3G had the lowest dose in the 3 CBCT scanners. These radiation doses were significantly higher than panoramic radiation doses (6.3 µSv -13.3 µSv).

Ludlow et al. (2006) and Pauwels et al. (2012) showed that radiation exposure dose of CBCT differ with the type of CBCT machine used and the FOV and the settings on the CBCT machine. Some machines, however, do not allow the settings to be changed. Radiation exposure also varies greatly per FOV, from 19 µSv for an upper jaw anterior region by Kodak 9000 3D.
(Pauwels et al., 2012) to 1073 µSv for the large FOV maximum quality CBCT by CB Mercuray (Ludlow et al., 2006).

Ludlow et al., (2013) has shown that the average effective dose of a child phantom is 36% higher than an adult phantom. This has been attributed to the higher position of the thyroid gland and the fact that children have more radiosensitive tissues than adults. In this study two different phantoms; a tissue equivalent phantom of a 10 yr. old child (ATOM model 706 HN; CIRS) and a tissue equivalent of average adult male phantom (ATOM Max model 711 HN; CIRS, Norfolk, VA) were used. OSL dosimeters were used. Four different scanning protocols were used to measure the effective dose:

- **High Resolution**: 360° rotation, 600 frames, 120 kVp, 5 mA, 7.4 seconds
- **Standard Resolution**: 360° rotation, 300 frames, 120 kVp, 5 mA, 3.7 seconds
- **Quickscan**: 180° rotation, 160 frames, 120 kVp, 5 mA and 2 seconds
- **Quickscan+**: 180° rotation, 160 frames, 90 kVp, 3 mA, and 2 seconds

The effective doses of FOV 13x16 cm ranged from 11-85 µSv for quickscan+ for the adult, 18-120 µSv for the child phantom for quickscan+, and standard protocol for both. This study also compared the results of past dosimetry studies using RANDO phantom and TLD dosimeters (Ludlow et al., 2006; Ludlow and Ivanovic, 2008; Pauwels et al., 2012). The results showed less than 2% difference so the data could be compared to the previous dosimeter studies (Ludlow and Walker, 2013). The low dose protocols are really valuable for acquiring the scans, however image quality degrades.

In the field of medical radiology, the applications of reconstructed algorithms have been applied to the cone-beam CT scans to reduce the radiation dose. Wang et al. (2009) has proposed
the use of an iterative image reconstruction algorithm based on a penalized weighted least-squares (PWLS) to reduce the CBCT dose. They proposed the use of low output tube current and an algorithm for improving the image quality of CBCT images.

The currently available literature on dosimetry of CBCT units is 87 to 206 µSv for a large field of view, such as a craniofacial scan (Ludlow et al., 2006; Silva et al., 2008). It is higher than the radiation exposure of the necessary conventional two dimensional orthodontic images; panoramic radiograph (14.2–24.3 µSv), lateral cephalogram (10.4 µSv), and full mouth series (13–100 µSv). The radiation dose of traditional 2D imaging techniques is equivalent to, or slightly lower than, CBCT imaging (Ludlow et al., 2006).

The three fundamental principles of radiological protection outlined in ICRP 2007 recommendations are: justification for an exposure, optimization and application of dose limits. Optimized radiation exposure is the least amount of radiation exposure required to produce a quality image to aid in clinical diagnosis. An image is considered good quality if it is sufficient to make a clinical diagnosis. The goal of every radiation exposure is to provide an image to answer a clinical question. The clinician should always aim for an optimized radiation exposure producing a quality image to answer the clinical question. Exposure should be limited to the area of interest, with low output radiation source.

The American Dental Association (ADA) in collaboration with the Food and Drug Administration (FDA) in 2004 published recommendations to help dentists expose their patients to as low as reasonably achievable (ALARA) radiation doses for all imaging modalities. Radiation exposure for any image should be optimized with the lowest radiation dose and acceptable quality
image to help answer a clinical question. These recommendations targeted the use of two-dimensional intra and extra oral radiographs (ADA Affairs, 2006).

The ADA has published recommendations for selection of an imaging technique. Their recommendation for CBCT use states that “clinicians should perform radiographic imaging, including CBCT, only after professional justification that the potential clinical benefits will outweigh the risks associated with exposure to ionizing radiation. However, CBCT may supplement or replace conventional dental x-rays when the conventional images will not adequately capture the needed information” (ADA Affairs, 2012).

CBCT use for orthodontic patients is becoming a concern because its use has increased exponentially for all aspects of orthodontic treatment. In 2010, an article "Radiation worries for children in dentist's chair" was published in The New York Times newspaper. In 2012, a point-counterpoint article on CBCT was published in the American Journal of Orthodontics and Dentofacial Orthopedics. This has stirred a lot of discussion about the use of CBCT. The 2013 position statement by the American Academy of Oral and Maxillofacial Radiology (AAOMR) provided some guidelines for the use of CBCT and also supported the statement on CBCT use by the ADA.

AAOMR provided four guidelines for CBCT use in orthodontic practice (AAOMR, 2013):

1. Image appropriately by applying image selection recommendations
2. Assess the radiation dose risk
3. Minimize patient radiation exposure
4. Maintain professional competency in performing and interpreting CBCT studies.
2.9 **Algorithms in CT, Micro-CT and CBCT**

Filtered back-projection (FBP) algorithms are used for the image reconstruction for medical CT. This was originally in use for FDK and its derivatives. When these are applied to the CBCT images, the image quality degrades dramatically. CBCT reconstruction has been done using the FDK algorithm. FDK software can be easily implemented into the CBCT hardware and has good computational efficiency.

The routine use of CBCT exposes the patient to a considerable amount of radiation, making it necessary to accept the low dose scanning protocol for young children. Low dose scanning is achieved by either reducing the number of projections or reducing the x-ray tube load milli-amperage (mAs). The FDK algorithm used with low mAs results in a noisy reconstructed projection. Algebraic reconstruction technique (ART) has been used for improving the image artifacts and noise in CBCT (Scarfe and Farman, 2008). Recent breakthroughs in compressed sensing has made it possible to achieve image quality comparable to the original image with low radiation dose (Ericson and Kurol, 2000). CS algorithms are able to do so by reconstructing an image with good quality from a scan with low x-ray tube load and reducing the number of projections. The results of the CS algorithms look promising for reducing the radiation dose, but other important parameters like computational efficiency will add a real value to the clinical use of CBCT. POCS and CS-WLS are other two algorithms proposed in material physics that reduce the radiation dose and give encouraging results for maintaining the image quality (Choi et al., 2010).
3. MATERIALS AND METHODS

3.1 Design and Sample

This was a prospective study designed to perform a subjective assessment of the image quality of two-dimensional x-ray images reconstructed from cone beam computed tomography obtained retrospectively from orthodontic records from the UIC archives. The scans were de-identified. Approval for this study was obtained from the University of Illinois Institutional Review Board (Research Protocol #2013-0815). Approval is available in Appendix A.

Two CBCT scans (image 1 and image 2) were acquired using the i-CAT Next Generation scanner (Imaging Sciences International, Hatfield, PA, USA) from two deidentified patients. The scan exposure parameters were 120 kVp, 5 mA and 0.3 voxel size. The deidentified patients were positioned in the machine with Frankfort horizontal parallel to the floor. The original CBCT scan of each patient projection data had 300 basis images. A reconstruction algorithm (RA) Adaptive-steepest-descent-projection-onto-convex-sets (ASD-POCS) was used to construct four CBCT scans from each original scan captured by the i-CAT machine. The reconstructed CBCT scans had the same number of basis images as the i-CAT (control), 50%, 25% and 11% of the original number of basis images.

A single 360° rotation of the x-ray tube for 20 sec on “Full” FOV 16cm (diameter) x 13cm (height) constructed 300 basis images. Primary reconstruction of the data was done by the CBCT machine after the data acquisition. Raw data was stored in DICOM format. The CBCT data was exported from the Xoran Cat (i-CAT manufacturer’s software) software in DICOM and imported into Dolphin 3D software (Version 11.7, Dolphin Imaging, Chatsworth, CA).
Images were displayed on six 20.1 inch (1909 W Dell computer model Precision T5600) screens with processor 1 Intel Xeon CPU E5-2603 and resolution 1440 x 900 at 60 hz operated at 32 bit. Five monitors were controlled by one main computer using a graphics Card (AMD Radeon HD 7870 2GB GDDR5). Computers were covered with thick black poster paper with a computer number on the outside and inside of the paper (Figure 1).

Figure 1. Computer Set up
Three reconstructions were performed on the projection data:

1) Reconstruction of a planar lateral cephalometric projection from the CBCT dataset using Dolphin 3D software

2) Reconstruction of a curved planar panoramic projection from the CBCT dataset using Dolphin 3D software

3) Reconstruction of a planar posterior-anterior cephalogram from CBCT dataset using Dolphin 3D software

3.1.1 Reconstruction of Lateral Cephalometric, PA Cephalometric and Panoramic Radiograph

Raw data from the i-CAT CBCT scans and the four reconstructed CBCT scans was uploaded in Dolphin 3D software (v. 11.7, Chatsworth, CA). Two dimensional x-rays were reconstructed by clicking the “Build Radiographs” on the left side (Figure 2). The image is selected as lateral, panoramic, or frontal ceph. The current version (11.7) of Dolphin 3D can generate 7 variations of the images (Dolphin 1, Dolphin 2, Dolphin 3, Ray-Sum, Emboss, MIP, and Trace filter). The Dolphin 1 filter was used with 0% magnification for all the images.

The first step in the reconstruction of the 2D radiographs was segmentation of the hard and soft tissues. Figure 2 shows the segmentation of hard and soft tissues.
The hard tissue segmentation was chosen from the upper left corner of the screen. The segmentation bar was adjusted so as to minimize the loss of cortical bone in thin bone areas. Images were segmented using the hard tissue segmentation tool for better representation of the bony structures without superimposition of the soft tissue and any artifacts.

After the segmentation of hard tissue, the 3D image was oriented from the front and profile by clicking the orientation on the screen on the lower left.

Figure 2. Hard and soft tissue segmentation by Dolphin 3D
Orientation of the 3D image from the frontal view was done by coinciding the upper and lower midlines through the mid sagittal plane and an axial plane (inter pupillary line) parallel to floor. Frontal orientation is followed by orientation from the profile view. Figure 3 shows the orientation of the 3D image from the frontal view.
The orientation of the 3D image on the right side was performed by orienting the Frankfort plane (Po- Or) parallel to the floor. Small adjustments were made for the bilateral structures (e.g. porion, gonion) to superimpose. Figure 4 shows the orientation from the right profile of the 3D volume.

Once a 3D volume was oriented, 2D radiographs were reconstructed by clicking the build radiograph icon. The following figures 5, 6, 7, and 8 demonstrate the reconstruction of the lateral cephalogram, panoramic, and posterior-anterior cephalogram.
3.1.2 **Reconstruction of a Planar Lateral Cephalogram from CBCT Dataset Using Dolphin 3D Software:**

Dolphin 1 filter and no image enhancement features were selected. The resultant image was copied and was used for the subjective analysis of image quality.
3.1.3 **Reconstruction of Curved Planar Panoramic Radiograph from CBCT Dataset Using Dolphin 3D Software**

For reconstruction of the panoramic radiograph, the following steps were followed. Panoramic view was selected after build radiographs was selected. This is done in two steps. The first step is to orient the image for construction of a panoramic radiograph.

![Figure 6. Reconstructions of curved planar reconstruction using Dolphin 3D](image)
The left-side boxes “Collimate” and “arch path” were changed so as to orient and include all the bony landmarks in the panoramic image. The second step in the construction of a panoramic view is to outline the dental arch path with cursor. Dental arch path was selected by either selecting the points with cursor or by selecting the anterior and posterior thickness.

Figure 7. Reconstruction of curved planar reconstructions using Dolphin 3D (continued)
3.1.4 Reconstruction of a Posterior-Anterior Cephalogram from CBCT Dataset Using Dolphin 3D Software

Reconstruction of a PA Ceph using Dolphin 3D was performed by selecting the image type and choosing the Dolphin 1 filter with no image enhancement features.

![Figure 8. Reconstruction of a PA Ceph using Dolphin 3D](image)
3.1.5 **Number of Images**

Dolphin3D was used to reconstruct 2D x-rays from the original i-CAT scan and also from four CBCT scans reconstructed using the RA. Table 1 shows the two dimensional x-rays that were reconstructed using the different CBCTs for each patient.

<table>
<thead>
<tr>
<th>Type of the image</th>
<th>i-CAT300</th>
<th>RA 300</th>
<th>RA 150</th>
<th>RA 79</th>
<th>RA 33</th>
</tr>
</thead>
<tbody>
<tr>
<td>Panoramic (Pano)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lateral Cephalogram (LC)</td>
<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>PA Cephalogram</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

A computerized set up was done in the orthodontic library. Six monitors of the same type (DELL 1909W) were used to project the two-dimensional radiographs. One computer with a graphic card managed five monitors. All monitors had similar display settings and were calibrated to the same degree. The computers were set up in a room where room lighting could be dimmed during the radiographic examination. Computer set was shown in figure 1.
Reconstructed two dimensional radiographic images were projected on the monitors using Microsoft PowerPoint 2013 (Microsoft, Redmond, WA, USA). Six copies of power point were uploaded to all six monitors. Radiographs reconstructed using different CBCT scans were randomized and were projected on the six different monitors. One i-CAT scan reconstructed image from each set was duplicated and projected on the first monitor. CBCT Data from two patients (image 1 and image 2) were shown in six sets of six images to the participants. Thirty six images were shown to all the participants in same order. The primary investigator was blinded as to the order of display of the 2D radiographs. The research assistant randomized the 2D radiographs. Figure 9 shows the randomization of the images reconstructed from CBCT scans with different number of basis images reconstructed using the ASD-POCS algorithm. The reconstructed 2D radiographs from CBCT image reconstructions were with full number of basis images (300), and reducing the number of basis images to 150, 79 and 33(Figure 9).
Subjects

Seventy three subjects were recruited from the UIC College of Dentistry. An email was sent to the UIC College of Dentistry faculty and residents of the departments of orthodontics, oral and maxillofacial surgery, and oral and maxillofacial radiology. One oral and maxillofacial radiologist was invited via personal email. 25 orthodontists, 8 oral surgeons, 11 surgery residents, 25 orthodontic residents, and two experienced oral and maxillofacial radiologists participated in
the survey. Only clinicians who have had experience evaluating digital images were invited to the study. On average, all participants use CBCT images to diagnose specific conditions and not for routine use. Once a reply to the recruitment email was received from an interested faculty member, a scheduled time was set for data collection.

3.3 **Description of the procedure**

The research evaluation was conducted in the library of the UIC Department of Orthodontics. All the images were projected in the previously determined randomized order reported above. The monitors were set in a row so the participant could see all monitors easily. There were six monitors projecting six pictures with two questions per set. All the monitors were covered with black paper with a computer number written on it. Images were assigned the same number as the computer.

Prior to data collection, an informed consent form was provided and the participant was given ten minutes to decide if he or she wanted to participate. The principal investigator was available in the room to answer any questions as needed. Each participant was assigned a random number for the convenience of scheduling and data collection. Participant’s responses remained completely anonymous.

Each participant was given a paper questionnaire to fill out with six sets of questions (Appendix B). Each set had two questions: the first question asked if the displayed image was diagnostically acceptable and the second question asked the participant to rank each image on a visual analog scale of 1 to 10 (1=poor quality and 10=best quality). Participants lifted the black paper covering the monitor to look at the images. Computer 1 had the black paper lifted at the beginning of the survey. The participant was asked to flip the black cover open to answer the first question and to leave it open once it was flipped open per each set of questions. The same protocol
was followed for all participants. After each set of questions, participants were asked to turn away so the next set of radiographs could be projected on the monitors and the black covers could be flipped down. Participants were not timed for the survey. Room lighting was dimmed the same amount for all the participants, however they were asked for their comfort zone and none of the participants asked to change the lighting setting once it was dimmed.

Each set of six images were randomly displayed on the monitors in the order recorded above, except for computer 1 which always displayed the original i CAT scan built radiographs. All images were evaluated for the following:

- Panoramic images - For diagnostic quality in a general screening (i.e., Is the image of diagnostic quality to view bone levels, trabeculation, and any pathology/ dental anomalies?) (Kwong et al., 2008).

- Lateral cephalogram images - For diagnostic quality to establish an orthodontic diagnosis (i.e., Is the image of diagnostic quality to locate landmarks such as sella, nasion, gonion, menton, and the relative positions of the maxilla to the cranial base, maxilla to the mandible, and the teeth in relation to their respective jaws) (Kwong et al., 2008).

- Posterio-anterior cephalogram - For their diagnostic quality in locating jugal point and bony and teeth midline asymmetries.

The same two questions were asked of all participants for all six sets of six images. The questionnaires are available in Appendix B.
3.4 **Data Collection**

Participant responses were recorded on paper questionnaires. The responses to the visual analog scale were measured by the principal investigator using 0-15 cm ruler. Figure 9 and figure 10 demonstrates the different types of radiographs and the questions related to them. A number from 1-10 was recorded for each response. The text documents were entered and rearranged with the data subsequently exported into a Microsoft Excel 2003 (Microsoft, Redmond, WA, USA) database.

![Image 1](image1.png)

Figure 10. Flow chart of data collection of images from image1.
3.5 Data Analysis

The data collection included two different sets of data: nominal and ordinal. For the nominal data set, a “yes” preference was recorded as 1 and a “no” preference as 0. For the ordinal data set, data were collected for the ranking (1-10) on a visual analog scale (VAS) for different
types of two dimensional x-ray images composed of different numbers of basis images. Data analysis was conducted using SPSS vs. 20 (Chicago, IL). An examination of the raw data showed that nonparametric tests were appropriate to analyze the data set. Cochran tests were used to assess if there were differences among the preferences of the image quality for five different sparse view image reconstructions for each of the three imaging techniques. McNemar tests were used to test proportion preference differences between pairs of different image reconstructions. Friedman tests were used to assess if there were differences among the rates of the image quality of the five different image reconstructions for all three imaging techniques. Wilcoxon tests were used to test rate differences between pairs of different image reconstructions.
4. RESULTS

4.1 Panoramic (Pano)

4.1.1 Image 1

This study showed a statistically significant difference among the preferences of examiner evaluating different panoramic images (p<0.05) using Cochran test. The frequency of choosing an image for clinical diagnosis was Pano 300 > Pano i-CAT > Pano 150 > Pano 79 > Pano 33 (Table II). McNemar test was used to evaluate the differences in the pairs. There was statistical difference (p<0.05) in all pairs except a pair of Pano 150- Pano i-CAT (p=1.00) (Table IV).

In the ranking of panoramic images from image 1, Friedman’s test showed a statistically significant difference (p=.000). The ranks of the images in descending order are Pano 300 > Pano i-CAT > Pano 150 > Pano 79 > Pano 33 (Table III). The highest mean rank was 4.21 (Pano 300) and the lowest rank was 1.42 (Pano 33). Wilcoxon test showed that the pairs with no statistically significant difference were Pano150-Pano i-CAT and Pano i-CAT-Pano 300 (P>0.05) (Table V).

4.1.2 Image 2

The results of Cochran test showed a statistically significant difference (p<0.05) in the preference of panoramic images reconstructed from different number of basis images in image 2. The frequency of preference in panoramic radiograph was Pano 300 > Pano 150 > Pano i-CAT > Pano 79 > Pano 33 (Table II). A McNemar test evaluated the differences in the pairs. The McNemar test showed that there was no difference amongst pairs of Pano 79- Pano i-CAT and Pano 150- Pano 300 (p>.05) (Table IV).

In ranking panoramic images from image 2, a Friedman’s test showed a statistically significant difference (p<0.05). The descending order of ranks was Pano 300 > Pano 150 > Pano i-CAT > Pano 79 > Pano 33 (Table III). The highest mean rank value was 4.64 (Pano 300) and lowest
mean rank was 1.06 (Pano 33). A Wilcoxon signed rank test evaluated the differences among the pairs of the images. All groups showed a statistically significant difference in ranking the images with different numbers of basis images (p>0.05) (Table V).

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FRIDMAN TEST DESCRIPTIVE STATISTICS FOR PANORAMIC RADIOGRAPH

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**TABLE IV**
RESULTS OF MCNEMAR TEST FOR PANORAMIC RADIOGRAPH

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* p-value statistically significant at ≤ 0.05

**TABLE V**
RESULTS OF WILCOXON TEST FOR PANORAMIC RADIOGRAPH

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* p-value statistically significant at ≤ .05
4.2 Lateral Cephalogram (LC)

4.2.1 Image 1

The results of the preferences for the lateral cephalogram radiographs from image 1 using Cochran test were statistically significant (p<0.05). The frequency of choosing an image was LC i-CAT > LC 300 > LC 79 > LC 150 > LC 33 (Table VI). A McNemar test evaluated the differences in the pairs. The pairs with no difference seen were LC 79 - LC 150, LC 79 - 300, LC 79 – i-CAT, LC 150 – LC 300, LC 150- LC i-CAT, and LC 300 – LC i-CAT (Table VIII).

In the ranking of lateral cephalogram images from image 1, Friedman’s test showed a statistically significant difference (p<0.05). The ranks of the images in descending order was LC 300> LC i-CAT> LC 79> LC 150> LC 33. (Table VII). The highest mean rank was 3.95 (LC 300) and the lowest value was 1.16 (LC 33). A Wilcoxon signed rank test evaluated the differences among the pairs of the images. The pairs with no difference seen were LC 79 - LC 150 and LC 300 – LC i-CAT (Table IX).

4.2.2 Image 2

The results of the preferences for lateral cephalogram images using Cochran test showed a statically significant difference (p<0.05). The images in order of their preference were LC 300> LC 150> LC i-CAT> LC 79> LC 33 (Table VI). A McNemar test evaluated the differences in the pairs. The groups of pairs that showed no difference were LC 79-LC i-CAT (p=.096), LC 150- LC i-CAT, and LC 150 – LC 300 (p>0.05) (Table VIII).

For ranking of the lateral cephalogram images from image 2, Friedman’s test showed a statistically significant difference (p<0.05). The descending order of ranks was LC 300> LC 150> LC i-CAT> LC 79> LC 33 (Table VII). The highest mean rank was 3.97 (LC 300) and the lowest mean rank of image was 1.71 (LC 33). Wilcoxon signed rank test evaluated the differences among
the pairs of the images. The groups that had no difference were LC i-CAT - LC 79 and LC 300-
150 (p>0.05) (Table IX).

**TABLE VI**

FREQUENCY OF DISTRIBUTION FOR LATERAL CEPHALOGRAM

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## TABLE VII

FRIDMAN TEST DESCRIPTIVE STATISTICS FOR LATERAL CEPHALOGRAM

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### TABLE VIII
RESULTS OF MCNEMAR TEST FOR LATERAL CEPHALOGRAM

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* p-value statistically significant at ≤ 0.05

### TABLE IX
RESULTS OF WILCOXON TEST FOR LATERAL CEPHALOGRAM

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* p-value statistically significant at ≤ .05
4.3 Posterior-Anterior Cephalogram (PA Ceph)

4.3.1 Image 1

The preferences among different PA ceph images reconstructed from images with different number of basis images were found to be different statistically using Cochran test (p <0.05). The images in order of their preferences in the descending order was PA i-CAT > PA 300 > PA 150 > PA 79 > PA 33 (Table X). A McNemar test evaluated the differences in the pairs. The groups that showed no difference were PA 150 – PA 300, PA 150 - PA i-CAT, and PA 300 – PA i-CAT (p>0.05) (Table XII).

In the ranking of the PA ceph image reconstructions from image 1, Friedman’s test showed a statistically significant difference (p<0.05). The ranks of the images in descending order were PA 300 > PA i-CAT > PA 150 > PA 79 > PA 33 (Table XI). The highest mean rank was of image PA 300 (4.04) and the lowest was PA 33 (1.29). Wilcoxon signed rank test evaluated the differences amongst the pairs of the images. The groups that showed no difference in the ranking were PA 150 – PA i-CAT (p>0.05) (Table XIII).

4.3.2 Image 2

A Cochran test was used to evaluate the difference in the preferences of the participants for PA ceph images reconstructed from image 2. There was a statistically significant difference in the preferences of the subjects for different PA ceph images reconstructed from CBCT composed of different numbers of basis images (p<.05). The descending order of preference was PA 300 > PA 150 > PA i-CAT > PA 79 > PA 33 (Table X). A McNemar test evaluated the difference amongst
the pairs. The groups that had no differences were PA 150- PA 300, PA 150- PA i-CAT, and PA 300- PA i-CAT (p>0.05) (Table XII).

In ranking of PA ceph images from image 2, Friedman’s test showed a statistically significant difference (p<0.05). The highest mean rank value was 4.23 (PA 300) and lowest was 1.16 (PA 33). The ranks of the images in descending order was PA 300> PA i-CAT> PA 150> PA 79> PA 33 (Table XI). Wilcoxon signed rank test evaluated the differences amongst the pairs of the images. The groups that showed no differences were PA i-CAT- PA 150 (p>0.05) (Table XIII).

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**TABLE X**
FREQUENCY OF DISTRIBUTION FOR PA CEPH
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RESULTS OF McNEMAR TEST FOR PA CEPH

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* p-value statistically significant at ≤ 0.05

### TABLE XIII
RESULTS OF WILCOXON TEST FOR PA CEPH

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* p-value statistically significant at ≤ 0.05
5. DISCUSSION

5.1 Applications of the Study

Cone beam computed tomography has its place in the diagnosis and treatment planning of complex cases. The use of CBCT is increasing as practitioners are adding a third dimension to the diagnosis and treatment planning of normal patients. The measurements are changing from lines to volumes. The real question is whether this third dimension should be used for all normal patients despite the radiation dose.

CBCT radiation dosage is affected by; scan time, the scanner settings used for the radiation exposure (kVp, mAs); pulsed radiation versus continuous beam; amount, type, and shape of the x-ray radiation filter; full 360° rotation versus 180° rotation; and the size of the FOV (limited or full) (Brooks, 2009). CBCT systems vary in the availability of operator-controlled settings.

There have been technological advancements both in software and hardware since the first commercially available CBCT. Advancements in hardware (radiation sensor technology and x-ray generation, ability to change the exposure parameters, availability of different FOVs, decreasing the scan time), software (computer technology and reconstruction algorithms), and operator knowledge have made great contributions towards decreasing the radiation exposure. The most common problem faced in decreasing the radiation dose is a decrease in the image quality.

Pulsed radiation exposure for acquiring a fewer number of projections is a great way to reduce the radiation exposure. This requires changes in the hardware of the machine. Currently, four units (Accuitomo, CB MercuRay, Iluma Ultra Cone, and Prexion 3D) provide continuous exposure.
Kwong et al. (2008) have shown that radiation exposure can be lessened by changing the exposure parameters for different FOVs. For the 6” FOV used for bitewings, the mA could be reduced to 5 mA and for 9” and 12” FOVs, it could be lessened to 2 mA while maintaining the image quality.

The field of view determines the overall amount of ionizing radiation. Since the effective dose of the ionizing radiation is computed from a weighted summation of effective dose to exposed organs, adding or removing some organs from the path of the x-ray beam will affect the effective dose. For example, limiting the area of exposure to a smaller FOV of either jaw reduces the dose compared to the exposure of the full craniofacial area. In orthodontics, if practitioners are not using CBCT for routine purposes, it is possible to reduce the dose without reducing the radiation exposure by exposing only the region of interest without exposing the entire craniofacial area.

Ludlow et al., (2013) have shown that reducing exposure parameters such as scan time, mA, and number of basis images could reduce the radiation dose dramatically. The study recommended quickscan+ protocols for low exposure scans, however reported that the quality of the images reconstructed using a low exposure scan were significantly deteriorated when compared to standard protocol. In the medical literature, problems of insufficient data linked to sparse views or gaps in the projection data of CT and CBCT have been studied. Insufficient data produces artifacts when the standard filtered back projection (FBP) algorithm is used. These artifacts have been resolved using other mathematical algorithms. Algorithms resolve this issue either by interpolating or extrapolating the missing data from the existing data, or by using iterative algorithms from existing measurements (LaRoque et al., 2008). This same principle can be used to intentionally create insufficient data to reduce the ionizing radiation exposure and retrieve the
data using an algorithm. The image quality of the images produced using the algorithms could be evaluated for their clinical use.

In this study both images 1 and 2, Pano 300 was consistently preferred and had higher mean rank than Pano i-CAT. In both rank and preference, Pano 150 and Pano i- CAT were not different statistically in image 1. In image 2, Pano 79 was not statistically different from Pano i-CAT in preference. So, this shows that the basis images could be reduced to 150 (image 1) and to 79 (image 2) while maintaining the image quality.

In lateral cephalogram images, image 1(LC 300) had higher mean rank than LC i- CAT. In preference, both images showed that LC 79 is not statistically significant different from LC i-CAT. So, the image quality of lateral cephalogram with reduced number of basis images (LC 79) was similar to i-CAT.

Both PA Ceph images show that PA ceph 300 was consistently ranked higher than PA ceph i- CAT. Among the pairs, PA ceph 150 was shown to be not statistically significant from PA ceph i-CAT. So, this shows that image quality of PA ceph 150 is similar to the PA ceph i-CAT.

The differences in results of number of basis images among different radiographs could be due to subjective analysis of the images. Quality assessment of two dimensional images reconstructed from CBCT by reconstruction algorithm ASD-POCS has shown that this algorithm has the ability to reduce the number of basis images for clinical diagnosis. The use of existing algorithm for reconstruction of images has shown to degrade image quality of images with reduced number of basis images (Ludlow et al., 2013). ASD-POCS improved the image quality of radiographs reconstructed from CBCT with same number of basis images i.e. RA 300 had higher mean rank and was preferred than i-CAT control. The minimum number of basis images
reconstructed radiographs (Pano, LC and PA ceph) RA 33 consistently had a lower rank and was not accepted for their diagnostic quality. The number of images could be reduced to 150 most of the times for diagnostic ability of 2D radiographs but also to 79 for lateral cephalogram landmark identification. It is worth noting that the lateral cephalogram required less number of basis images to be regarded as diagnostic. One possibility is that majority of the participants have undergone orthodontic training which focuses on rigorous cephalometric tracing and analyses, thus landmark identification is easier than that with the less commonly used PA ceph.

5.2 **Strengths of the study**

This study was a prospective study that involved recruiting participants from the specialties that use CBCT for diagnosis and treatment planning. Seventy-three subjects evaluated the study images for diagnostic quality. The subjects had exposure to the CBCT imaging modality both didactically and clinically.

2D radiographs were reconstructed from CBCT scans and their reconstructed sparse view reconstructions (300, 150, 79 and 33). Subjects ranked different images on a visual analog scale. One of the strengths of this approach was that by repeating the exercise with multiple images or among different observers, their agreement was an indicator of superiority qualitatively. The principal investigator and subjects were blinded for the order of display of the images. All the images were randomized.

This is the first study to use a reconstruction algorithm in the dental literature aiming to reduce the number of basis images to reduce the radiation scan time and radiation exposure. This study is applicable to the clinical practice of orthodontics, and dental practice in general. The
A growing topic of debate whether to use CBCT for routine purposes will have support if the radiation risks to the patient are minimized by reducing the radiation dose.

Experimental conditions such as room lighting and the monitor screens were standard for all the examiners. No examiners had visual impairment. The study was performed on patient CBCT scans. All reported image quality and radiation dosimeter studies in dentistry have been on phantoms and human cadavers.

This algorithm, if introduced to the commercial CBCT market, will demand no changes in hardware as suggested by Ludlow et al., (2013) and Kwong et al., (2008).

5.3 **Limitations of the study**

The inherent examiner bias for the utility of CBCT based on their training and knowledge may have caused changes in their responses to evaluation of the images. The examiner could not change the image quality by manually changing the image, a fixed setting was chosen by the principal investigator for all sets of images.

5.4 **Future studies**

The most popular algorithm currently used for CBCT images is FDK. ASD-POCS has the ability to retrieve the missing data by using the existing data. FDK has shown to produce artifacts due to the insufficient data. ART has been shown to decrease the effect of the artifacts (Scarfe and Farman, 2008). ASD-POCS can generate high quality images with less projection data but the computational efficiency of the algorithm ASD-POCS should be tested against other available commercial algorithms.
The image quality of the images obtained using different algorithms with lesser projection data could be compared. Since this study was a subjective evaluation of the images, all the examiners could be calibrated in advance to look for the landmarks on the images so the subjectivity bias could be lessened.

The low exposure protocols recommended in the literature are established by calculating the effective doses for the average male child and adult. More studies should be conducted taking other ethnicities and females into consideration.

The potential studies for utilization of these algorithms by dental radiology departments are unlimited. The use of an algorithm to reduce the number of basis images, while maintaining the image quality necessary for the clinical use is discussed here. The potential use of these algorithms for commercially available maxillofacial CBCT systems should be evaluated by future studies.
6. CONCLUSION

In conclusion, the qualitative assessment of images constructed from the sparse view image reconstruction using a reconstruction algorithm produced significant results (p<0.05). For all two-dimensional radiographs: panoramic, lateral cephalogram, and posterior-anterior cephalogram, image reconstructions with RA 300 produced consistently similar or better results when compared to the i-CAT control in terms of individual preference and mean rank. In the panoramic radiograph and posterior anterior cephalogram, the images reconstructed from the RA 300 and 150 had similar image quality to the i-CAT control. In the lateral cephalogram reconstructions, the images reconstructed from the RA 300, 150, and 79 had similar image quality to the i-CAT control. This study shows that the image quality of images reconstructed using the sparse view image reconstruction utilizing a reconstruction algorithm ASD-POCS could be maintained while reducing the basis images to reduce patient radiation exposure.
Exemption Granted

September 16, 2013

Pardeep Kaur, DDS
Orthodontics
801 S. Paulina Ave., Rm 131
M/C 841
Chicago, IL 60612
Phone: (757) 401-5091 / Fax: (312) 996-0873

RE: Research Protocol # 2013-0815
“Evaluation of Image Quality of Radiographic Orthodontic Records Derived from CBCT”

Sponsors: None

Dear Dr. Kaur:

Your Claim of Exemption was reviewed on September 16, 2013 and it was determined that your research meets the criteria for exemption. You may now begin your research.

Performance Site: UIC
Subject Population: Adult (18+ years) subjects only
Number of Subjects: 80

The specific exemption category under 45 CFR 46.101(b) is:
(2) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures or observation of public behavior, unless: (i) information obtained is recorded in such a manner that human subjects can be identified, directly or through identifiers linked to the subjects; and (Yuasa et al.) any disclosure of the human subjects' responses outside the research could reasonably place the subjects at risk of criminal or civil liability or be damaging to the subjects' financial standing, employability, or reputation.
APPENDIX A (continued)

You are reminded that investigators whose research involving human subjects is determined to be exempt from the federal regulations for the protection of human subjects still have responsibilities for the ethical conduct of the research under state law and UIC policy. Please be aware of the following UIC policies and responsibilities for investigators:

1. **Amendments** You are responsible for reporting any amendments to your research protocol that may affect the determination of the exemption and may result in your research no longer being eligible for the exemption that has been granted.

2. **Record Keeping** You are responsible for maintaining a copy all research related records in a secure location in the event future verification is necessary, at a minimum these documents include: the research protocol, the claim of exemption application, all questionnaires, survey instruments, interview questions and/or data collection instruments associated with this research protocol, recruiting or advertising materials, any consent forms or information sheets given to subjects, or any other pertinent documents.

3. **Final Report** When you have completed work on your research protocol, you should submit a final report to the Office for Protection of Research Subjects (OPRS).

4. **Information for Human Subjects** UIC Policy requires investigators to provide information about the research protocol to subjects and to obtain their permission prior to their participating in the research. The information about the research protocol should be presented to subjects in writing or orally from a written script. **When appropriate,** the following information must be provided to all research subjects participating in exempt studies:
   a. The researchers affiliation; UIC, JBVMAC or other institutions,
   b. The purpose of the research,
   c. The extent of the subject’s involvement and an explanation of the procedures to be followed,
   d. Whether the information being collected will be used for any purposes other than the proposed research,
   e. A description of the procedures to protect the privacy of subjects and the confidentiality of the research information and data,
   f. Description of any reasonable foreseeable risks,
   g. Description of anticipated benefit,
   h. A statement that participation is voluntary and subjects can refuse to participate or can stop at any time,
   i. A statement that the researcher is available to answer any questions that the subject may have and which includes the name and phone number of the investigator(s).
   j. A statement that the UIC IRB/OPRS or JBVMAC Patient Advocate Office is available if there are questions about subject’s rights, which includes the appropriate phone numbers.

Please be sure to:

> Use your research protocol number (2013-0815) on any documents or correspondence with the IRB concerning your research protocol.
APPENDIX A (continued)

We wish you the best as you conduct your research. If you have any questions or need further help, please contact the OPRS office at (312) 996-1711 or me at (312) 355-2908. Please send any correspondence about this protocol to OPRS at 203 AOB, M/C 672.

Sincerely,

Charles W. Hoehne
Assistant Director
Office for the Protection of Research Subjects

cc: Carlotta A. Evans, Orthodontics, M/C 841
    Budi Kusnoto, Orthodontics, M/C 841
APPENDIX B

QUESTIONNAIRE

Instructions:

There will be six images projected on six monitors in front of participants in department of orthodontics library. The monitors will be set in a row so the participant could see all monitors easily. There will be six sets of projecting 6 pictures with two questions per set. All the monitors will be covered with a black paper with a computer number written on it. Images are assigned the same number as the computer. Participant can lift the black paper to look at the images. Computer 1 will have the black paper lifted up. Participant will lift the paper to look at each image. Participant will be given one minute and a half (90 sec) to view all the images and to answer the first question.

For panoramic images, for their diagnostic quality for a general screening (ie, is the image of diagnostic quality to view bone levels, trabeculation, and any pathology/dental anomaly).

For lateral cephalogram images, for their diagnostic quality to make an orthodontic diagnosis (ie, Is the image of diagnostic quality to locate the landmarks such as sella, nasion, gonion, menton, relative positions of the maxilla to the cranial base, maxilla to the mandible and the teeth in relation to their respective jaws).

For posterio-anterior cephalogram, for their diagnostic quality for locating Jugal point and bony and teeth midline asymmetries.
APPENDIX B (continued)

Set 1, Question 1, Is this image diagnostically acceptable? Circle the response.

Image 1: Y/N

Image 2: Y/N

Image 3: Y/N

Image 4: Y/N

Image 5: Y/N

Image 6: Y/N

Question 2, Rank the images on a visual analog scale for their diagnostic image quality. 1 being poor image quality and 10 as the excellent image quality.

Image 1:

Poor ___________________________ Excellent

Image 2:

Poor ___________________________ Excellent

Image 3:

Poor ___________________________ Excellent

Image 4:

Poor ___________________________ Excellent

Image 5:

Poor ___________________________ Excellent

Image 6:

Poor ___________________________ Excellent
APPENDIX B (continued)

Set 2, Question 1, Is this image diagnostically acceptable? Circle the response.

Image 1: Y/N
Image 2: Y/N
Image 3: Y/N
Image 4: Y/N
Image 5: Y/N
Image 6: Y/N

Question 2, Rank the images on a visual analog scale for their diagnostic image quality. 1 being poor image quality and 10 as the excellent image quality.

Image 1: 

Poor  ______________________________________________________________________ Excellent

Image 2: 

Poor  ______________________________________________________________________ Excellent

Image 3: 

Poor  ______________________________________________________________________ Excellent

Image 4: 

Poor  ______________________________________________________________________ Excellent

Image 5: 

Poor  ______________________________________________________________________ Excellent

Image 6: 

Poor  ______________________________________________________________________ Excellent
Set 3, Question 1, Is this image diagnostically acceptable? Circle the response.

Image 1: Y/N
Image 2: Y/N
Image 3: Y/N
Image 4: Y/N
Image 5: Y/N
Image 6: Y/N

Question 2, Rank the images on a visual analog scale for their diagnostic image quality. 1 being poor image quality and 10 as the excellent image quality.

Image 1:
Poor ———————————————————————————— Excellent

Image 2:
Poor ———————————————————————————— Excellent

Image 3:
Poor ———————————————————————————— Excellent

Image 4:
Poor ———————————————————————————— Excellent

Image 5:
Poor ———————————————————————————— Excellent

Image 6:
Poor ———————————————————————————— Excellent
Set 4, Question 1, Is this image diagnostically acceptable? Circle the response.

Image 1: Y/N
Image 2: Y/N
Image 3: Y/N
Image 4: Y/N
Image 5: Y/N
Image 6: Y/N

Question 2, Rank the images on a visual analog scale for their diagnostic image quality. 1 being poor image quality and 10 as the excellent image quality.

Image 1:
Poor                                      Excellent

Image 2:
Poor                                      Excellent

Image 3:
Poor                                      Excellent

Image 4:
Poor                                      Excellent

Image 5:
Poor                                      Excellent

Image 6:
Poor                                      Excellent
APPENDIX B (continued)

Set 5, Question 1, Is this image diagnostically acceptable? Circle the response.

Image 1: Y/N
Image 2: Y/N
Image 3: Y/N
Image 4: Y/N
Image 5: Y/N
Image 6: Y/N

Question 2, Rank the images on a visual analog scale for their diagnostic image quality. 1 being poor image quality and 10 as the excellent image quality.

Image 1:

Poor __________________________________________ Excellent

Image 2:

Poor __________________________________________ Excellent

Image 3:

Poor __________________________________________ Excellent

Image 4:

Poor __________________________________________ Excellent

Image 5:

Poor __________________________________________ Excellent

Image 6:

Poor __________________________________________ Excellent
Set 6, Question 1, Is this image diagnostically acceptable? Circle the response.

Image 1: Y/N

Image 2: Y/N

Image 3: Y/N

Image 4: Y/N

Image 5: Y/N

Image 6: Y/N

Question 2, Rank the images on a visual analog scale for their diagnostic image quality. 1 being poor image quality and 10 as the excellent image quality.

Image 1:

Poor  ________________________________________________________________________ Excellent

Image 2:

Poor  ________________________________________________________________________ Excellent

Image 3:

Poor  ________________________________________________________________________ Excellent

Image 4:

Poor  ________________________________________________________________________ Excellent

Image 5:

Poor  ________________________________________________________________________ Excellent

Image 6:

Poor  ________________________________________________________________________ Excellent
APPENDIX C

TABLE XIV
RESULTS OF COCHRAN TEST FOR PANORAMIC RADIOGRAPH

<table>
<thead>
<tr>
<th></th>
<th>Image 1</th>
<th>Image 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cochran's Q</td>
<td>179.285(^a)</td>
<td>141.987(^a)</td>
</tr>
<tr>
<td>Asymp. Sig.</td>
<td>.000(^*)</td>
<td>.000(^*)</td>
</tr>
</tbody>
</table>

* p-value statistically significant at ≤ 0.05

TABLE XV
RESULTS OF FRIEDMAN TEST FOR PANORAMIC RADIOGRAPH

<table>
<thead>
<tr>
<th></th>
<th>Image 1</th>
<th>Image 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chi-Square</td>
<td>188.737</td>
<td>215.916</td>
</tr>
<tr>
<td>Asymp. Sig.</td>
<td>.000(^*)</td>
<td>.000(^*)</td>
</tr>
</tbody>
</table>

* p-value statistically significant at ≤ 0.05

TABLE XVI
RESULTS OF CONCHRAN TEST FOR LATERAL CEPHALOGRAM

<table>
<thead>
<tr>
<th></th>
<th>Image 1</th>
<th>Image 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cochran's Q</td>
<td>126.336(^a)</td>
<td>82.734(^a)</td>
</tr>
<tr>
<td>Asymp. Sig.</td>
<td>.000(^*)</td>
<td>.000(^*)</td>
</tr>
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</table>

a. 0 is treated as success

* p-value statistically significant at ≤ 0.05
### APPENDIX C (continued)

#### TABLE XVII
RESULTS OF THE FRIEDMAN TEST FOR LATERAL CEPHALOGRAM

<table>
<thead>
<tr>
<th></th>
<th>Image 1</th>
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</thead>
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<tr>
<td>Chi-Square</td>
<td>149.413</td>
<td>111.077</td>
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<tr>
<td>Asymp. Sig.</td>
<td>.000*</td>
<td>.000*</td>
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</table>

* p-value statistically significant at ≤ 0.05

#### TABLE XVIII
RESULTS OF COCHRAN TEST FOR PA CEPH

<table>
<thead>
<tr>
<th></th>
<th>Image 1</th>
<th>Image 2</th>
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<tr>
<td>Cochran's Q</td>
<td>138.486a</td>
<td>160.769</td>
</tr>
<tr>
<td>Asymp. Sig.</td>
<td>.000*</td>
<td>.000*</td>
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</table>

* p-value statistically significant at ≤ 0.05

#### TABLE XIX
RESULTS OF FRIEDMAN TEST FOR PA CEPH

<table>
<thead>
<tr>
<th></th>
<th>Image 1</th>
<th>Image 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chi-Square</td>
<td>142.858</td>
<td>162.142</td>
</tr>
<tr>
<td>Asymp. Sig.</td>
<td>.000*</td>
<td>.000*</td>
</tr>
</tbody>
</table>

* p-value statistically significant at ≤ 0.05
CITED LITERATURE


NAME: Pardeep Kaur

EDUCATION: B.D.S, Dashmesh Institute of Research and Dental Sciences, Faridkot, India, 2005
D.D.S., University of Illinois at Chicago, Chicago, IL, 2011
M.S., Oral Sciences, University of Illinois at Chicago, Chicago, IL, 2014
Certificate, Orthodontics, University of Illinois at Chicago, Chicago, IL, 2014

HONORS: Clinic and Research Day Award, 2011
American Institute of Orthodontics Award, 2011
The American Academy of Esthetic Dentistry Senior Student Award, 2011

PROFESSIONAL MEMBERSHIP: American Association of Orthodontists
American Dental Association
Chicago Dental Society
Illinois Society of Orthodontists