University of Alberta

Accuracy of Digital Scanning Cephalometric Radiographic Units

by

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Abstract

Objective: The purpose of this study was to determine if there were differences between measurements made on lateral cephalometric images obtained from CCD scanning lateral cephalometric units and their manufacturers' static lateral cephalometric counterparts in 1) linear, angular, and magnification of a radiographic phantom and 2) linear and angular measurements of a marked human dry skull.

Methods: Lateral cephalometric radiographs were obtained at three separate distances on a radiographic phantom and a human dry skull from four cephalometric radiography units. The images were used to measure distance, angles, and magnification variables.

Results: Statistically significant differences were found between the Orthoceph OC 100 D and the Orthoceph OC 100 and between the Orthophos DS and Orthophos CD for linear, angular and magnification factors. Clinically significant differences were not found between machines, except in magnification.

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Chapter 1 - Introduction and Literature Review

1.1 Literature Review

1.1.1 Introduction

Orthodontic treatment planning relies on multiple diagnostic criteria. A clinical examination of the patient, diagnostic models and radiographs are used in conjunction by orthodontists to identify skeletal and dental problems leading to malocclusions. One of the radiographs used during treatment planning is the lateral cephalometric radiograph. Cephalometry is an important tool in orthodontic diagnosis, treatment planning, evaluation of treatment results, and prediction of growth.

In the past ten years digital radiography has become more available and more widely used in dental offices because of many benefits it offers over traditional film based radiography. Digital radiography allows immediate image acquisition, computer archiving, computer aided cephalometric analysis, radiation dose reduction, and the environmental benefit of no processing chemicals.[1]

The new digital cephalometric units are being used in increasing number orthodontic offices because of their efficiency. With new computer aided cephalometric analyzing programs they cut down on treatment planning time. Orthodontists no longer have to manually trace cephalometric radiographs and measure each angle with a protractor and each line with a ruler. With new direct digital units the images can go directly to a computer with cephalometric analyzing software. Direct digital units have also saved costly clinic space that was once used by darkrooms to process conventional film radiographs. With no processing there are no more caustic chemicals to be bought, stored, handled, and disposed of by dental offices.[2] With all of these advantages, it is not surprising that orthodontists are excited about this new technology and are willing to invest the extra money to have one of these units in their office. Since the primary purpose of these machines is for diagnosis and treatment planning, it is important to know if diagnostic quality is being sacrificed for efficiency.

Currently there are multiple varieties of imaging projections for cephalometric radiography. Traditional film-based cephalometric imaging uses a pyramid shaped x-ray beam that is applied in a static manner. For direct digital cephalometry there are two modes of image acquisition, static and scanning. Of the scanning units, there is horizontal and vertical scanning, and these produce significantly different projection geometries when compared with traditional film-based cephalometric units. The CCD cephalometric machines have fan shaped x-ray beams that scan vertically or horizontally. Because cephalometric radiographs are used in diagnosis and treatment planning, it is important to determine if distortion of the image is created by the projection geometry of the scanning direct digital cephalometric units in comparison to their static film based counterparts. If distortions are produced, then the diagnostic value of the cephalometric analysis would be deceased. Since most digital radiographs are analyzed using computer programs that were originally made for scanned film images, the programs use static cephalometric measurement norms that have an accepted inherent magnification from traditional cephalometric films. If the magnification differences are great enough to increase or decrease linear or angular measurements it could affect the analysis outcome.

1.1.2 Historical Perspective

Correction of measurement errors in cephalometrics used in orthodontics has been a topic of discussion since Broadbent introduced his 1931 paper, "A New X-ray Technique and Its Application in Orthodontia".[3] In it, he describes taking a lateral cephalogram and correcting for magnification errors created by non-parallel x-ray beams by knowing "the predetermined target distance, five feet, and film distance". The positioning of patients in relation to the film has not changed significantly since. A patient is still positioned 5 feet from the x-ray tube and the central ray of the x-ray beam passes along the length of the ear posts along their superior surfaces and meets the midsagittal plane and the film surfaces at right angles as was described by Brodie in 1949. [4] In the same paper Brodie discusses correction of measurements by using a leaded aluminum scale that is always attached to the midsagittal plane that will appear on the final radiograph. This scale can then be used to estimate magnification. In 1940, Adams wrote "the value of all x-ray pictures depends on three major properties. They are (1) the proper contrast density, (2) sharpness of detail and (3) the degree of distortion of figure.". [5] The same issues continue today when using cephalometrics in orthodontics. The issues of contrast, density and sharpness of detail were improved with imaging techniques and better film quality. Contrast and density relate to errors of identification, the ability to identify the specific anatomical landmarks on cephalograms. There have been multiple studies addressing landmark identification error. [6-12] The addition of digital cephalometrics reintroduced concerns regarding contrast and density due to the different modes of image acquisition. And with the changes in x-ray beam geometry with scanning digital cephalometric units the issue of distortion is again in question.

1.1.3 Digital Imaging

Radiographic images can be produced by an analog process or by a digital process. A conventional film image is created by the interaction of ionizing radiation and the silver halide emulsion in x-ray film. In contrast, a digital image is created when the ionizing radiation interacts with discrete picture elements (pixels) located on an x-ray sensitive plate or solid state receptor.[13] The location of each pixel is identified by row and column coordinates within the image matrix.[14] Digital mages can be acquired by means of a photo-stimulated or storage phosphor plate (PSP), charge coupled device (CCD) receptors, or digitization of radiographic film with computer scanners. [15,16] Spatial resolution and gray scale display are two of the most important characteristics of digital imaging. The line pair (lp) is the unit of measurement for spatial resolution, and refers to the largest number of paired lines visible in 1mm. The number and size of a pixel determines the spatial resolution, therefore the more pixels and the smaller their size, the greater the spatial resolution. The standard computer monitor can display an 8 bit image, that is, 2^8 or 256 levels of gray. The human eye can only detect 15 to 25 shades of gray. Higher gray scales are desirable when enhancing image with computer aided software.

1.1.3.1 Photo-stimulated Storage Phosphor Plates

The majority of the studies comparing digital cephalograms with film based cephalograms use photostimulatable phosphor plates. These plates are thin, wireless, and flexible similar to intensifying screens. [13] They are able to be retrofitted into an existing x-ray cassette in place of film. The plates are read by a laser scanner that detects the location of the stored energy and once released, this data is input it into a computer program that creates the digital image made up of pixels. The x-ray beam geometry and therefore, relative magnification, are unchanged. The phosphor plates still require a processing time in the scanner of approximately 3 minutes depending on the product. The plates are reusable after the latent image is removed by exposure to high intensity light.[17] The resolution of these systems is greater than 4 lines per millimeter.

1.1.3.2 Charge Couple Devices (CCD)

Because of initial size limitations, charge couple devices (CCDs) were originally only used to replace intraoral film. The analog electric signal is digitized and converted to an image by computer software. CCD images require no processing and can be viewed within seconds after exposure of the CCD. To compensate for the cost of creating a single CCD that would capture the full area of a skull, a linear CCD array has been combined with a scanning slit shaped x-ray beam.[14] As CCD extraoral technology has progressed there are two ways in which images are captured by these units. One type of unit scans the patient vertically with a CCD receptor that is placed horizontally and coupled to the fan-shaped horizontally collimated x-ray beam, while the other type horizontally scans with a CCD receptor that is coupled with a V-shaped x-ray beam.[18] The direction of the beam produces a different projection geometry, which could cause distortion differences between CCD machines as well as between CCD and conventionally acquired images.

1.1.3.3 Indirect Digital Imaging

A conventional film image can be digitized through scanning with a flatbed scanner and a transparency adaptor. The analog image is converted to pixels representing the grayscale of the original image. The computer monitor displays images in dots per inch (dpi), where the dots are the pixels. The number of dots is directly proportional to image detail. Scanners allow the selection of dpi setting prior to scanning. In an article by Halazonetis[19], he recommends scanning images at 150 dpi. He points out that this resolution is greater than most computer monitors can display, so the advantage would come into play when zooming in on a specific landmark. In a study on minimum scanner settings where the scanner settings ranged from 75 dpi to 600dpi black and white, and 75 to 200 dpi color. The black and white images were scanned with a 256 grayscale, while the color images were scanned with a 256 color red green blue (RGB) scheme. The results demonstrated no significant difference in landmark identification between scanner settings.[20] There was a perceived improvement in image quality for the images scanned in color compared to those scanned in black and white by the examiners. Another study showed images scanned at a resolution of 300 dpi had comparable landmark identification reliability as analogue identification.[21]

1.1.4 Landmark Reliability

The accuracy of recognition of cephalometric landmarks is critical for proper diagnosis of malocclusion and for assessing growth and orthodontic treatment. Multiple studies have been published comparing landmark reliability between conventional film based cephalometric images, digitized radiographic films, and digital storage phosphor plate images. Forsyth[22] found the random error associated with angular and linear measurements recorded on the digital images were greater than on the conventional radiographs. In addition, they found there was a systematic error producing statistically significant differences in the majority of angular and linear measurements between the digital images and the conventional radiographs. The study noted in a cephalometric situation where a high degree of accuracy is required the errors that occurred with some measurements were of sufficient magnitude to be of clinical significance. It is important to note that this study used a video camera to digitize the image which is a different method than most images are digitized now. Also the linear measurement difference ranged from 0.1 to 1.6 mm, while the angular measurement difference ranged from 0.2 to 2.2 degrees. Clinically, both of these differences may not be significant to diagnosis.

In the study by Geelen [12]the reproducibility of cephalometric landmarks on conventional films, and images acquired by storage phosphor digital radiography both on hardcopy and monitor-displayed versions was evaluated and compared. In this paired samples experiment, the images were obtained simultaneously using a single radiation exposure. They found a statistically significant difference between the reproducibility of film, hardcopy and monitor-displayed images in 11 of the 21 landmarks but they did not find an equivocal trend that one modality was always the best. And even though a lower reproducibility was seen for the monitor-displayed images they concluded it was probably of little clinical significance. An important aspect of this study in comparing it to other studies of landmark reliability in digital imaging is that it used a monitor, which is the most common way to view and analyze digital images.

In contrast to the decreased landmark recognition found in the above studies

Hagemann [23] found the average reproducibility of cephalometric landmarks was significantly higher on the digitally obtained images. Their study compared the reproducibility of cephalometric landmarks on conventional and digital lateral head films. Hard copies of 100 digital and 100 conventional lateral head films of patients were compared. For the digital cephalograms, storage phosphor plates in standard X-ray cassettes were used.

In a recent study the reproducibility and reliability of digitization of landmarks was assessed comparing manual tracing and indirect digitization followed by measurement with Dolphin Imaging Software (Version 8.0).[24] Sixty lateral cephalograms were evaluated by the two methods. Reliability was determined by duplicate measurement and reproducibility was evaluated by comparing both techniques. The findings indicated that both techniques were at the 95% level. It was noted that the magnification of the image must be known to properly calibrate the program in order to achieve reliable measurements.

The current review of the literature identified only one study that compared landmark identification reliability on direct digital (CCD) with that of conventional film. [25] In that study only the vertically scanning, Orthophos DS Ceph from Sirona Dental Systems, CCD unit was used. The limitations of this study were that only six landmarks were chosen and the display conditions were not the same during tracing. They found comparable errors in landmark identification for both the conventional and CCD machines.

1.1.5 Radiation Dose Reduction

Radiation dose reduction was one of the major reported benefits to patients when using digital radiographs. The Hagemann study described above also reported a reduction of radiation exposure of 23.7% in the digital images.[23] This was measured by recording the exposure settings for the digital x-rays compared to the conventional x-rays. On average 11.54±1.42 mAs were used for the digital x-rays and 15.09±2.29 mAs for the conventional x-rays.

In a study by Gijbels et al[26], the diagnostic yield of conventional and digital cephalometric images as defined by radiation dose and diagnostic performance was studied in human cadavers, using photo-stimulated storage phosphor plate for the digital images. By measuring amount of residual radiation in the organs exposed, the study showed that using digital radiology could effectively lower the radiation dose without compromising the diagnostic yield of the images. Previously, Naslund et al. [27], found dose reductions of 50% and 75% respectively were obtained by placing three storage phosphor image plates in the same cassette. Lateral cephalograms were exposed on ten patients in this study. And the study concluded that a dose reduction of 75% does not affect the localization of anatomical landmarks in lateral cephalograms.

In 2001, Visser et al[28] compared a scanning CCD to a conventional unit. The conventional radiographs were exposed with a Siemens Orthophos C unit (77 kV, 14 mA, 0.5 s) and a film-screen system of a relative speed of 400. The direct-digital radiographs were exposed with a Siemens Orthophos DS Ceph. An anthropomorphic phantom was positioned to expose lateral cephalographs from the patient's left side. The results demonstrate that scanning direct-digital cephalometric radiography cut the patient's dose in half compared with the conventional screen-film technique even though exposure time was increased from 0.5 seconds to 15.8 seconds. The study concluded that direct-digital cephalometry is more advantageous than the conventional technique from the perspective of radiation protection. These studies give impetus to using digital radiography. They have shown that in digital radiography the dose reduction does not effect the diagnostic information in the radiographs obtained, but there is a significant difference in x-ray beam geometry between photo-stimulated phosphor plate digital radiography and scanning CCD digital radiography.

1.1.6 Projection Errors

When evaluating projection errors, previous studies dealt mostly with patient positioning and the effect on landmark identification. The effect of projection errors caused by incorrect patient positioning should be considered as part of the random errors in cephalometric measurements. The effect of head rotation in the vertical Z-axis on lateral cephalometric radiographs was reported by Yoon et al..[29] Lateral cephalometric radiographs were taken of seventeen human dry skulls were rotated vertically from 1 to 15 degrees. The horizontal linear measurements decreased as the length of the rotational angle toward the film increases, at 15 degrees the maximum error was 5.78%. The vertical linear measurements increase as the length of the rational angle toward the film increases, at 15 degrees the maximum error was -1.49%. The horizontal linear measurements have more projection errors than vertical measurements. The vertical head rotation demonstrated little effect on angular measurements.

The effect of incorrect patient positioning on linear and angular measurements was reported by Ahlqvist et al.[30,31] When the misalignment of the patient's head was less than 5 degrees, the errors were generally less than 1% in length measurement and less than 1 degree in angle distortion. A misalignment of the patient's head of more than

5 degrees could be easily detected by the operator and should be corrected immediately. Differences in magnification are rarely assessed in cephalometric studies involving projection errors because the method of image acquisition has been standardized for so many years. The inherent distortion found in cephalometric radiographs has been accepted because it is a two dimensional representation of a three dimensional object. Due to the pyramidal shape of the x-ray beam the right and left sides can not be superimposed exactly. The structures on the side closest to the image receptor are magnified less than the opposite side.[14]

Cephalometric analysis of lateral head films is an important tool in orthodontic diagnosis and treatment planning. The analysis serves as an integral instrument in diagnosis and prognosis of each case. [23] The major sources of error in cephalometric analysis include radiographic film magnification, tracing, measuring, recording, and landmark identification.[6,32,33] The usefulness of results obtained with cephalometrics is limited by measurement error.

1.2 Research Questions

Paper #1

1. Is there a difference between the calculated magnification indexes of separate linear measurements from lateral cephalometric images obtained at decreasing distances from the x-ray source within the same lateral cephalometric radiography unit?
2. Is there a difference between the calculated magnification indexes from lateral cephalometric images obtained at the same distance from the x-ray source in scanning and static lateral cephalometric radiography units made by the same manufacturer?
3. Is there a difference between angular measurements in lateral cephalometric images obtained from scanning and static lateral cephalometric radiography units made by the same manufacturer?
4. Is there distortion in images obtained from lateral cephalometric radiography units?

Paper #2

1. Is there a difference between linear measurements from lateral cephalometric images obtained from scanning and static lateral cephalometric radiography units made by the same manufacturer?
2. Is there a difference in angular measurements between lateral cephalometric images obtained from scanning and static lateral cephalometric radiography units made by the same manufacturer?
3. Is there a clinically significant difference in linear and angular measurements between lateral cephalometric images obtained from scanning and static lateral cephalometric radiography units made by the same manufacturer?

1.3 Null Hypothesis

Paper #1

1. There is no difference between the calculated magnification indexes of separate linear measurements from lateral cephalometric images taken at the decreasing distances from the x-ray source within the same lateral cephalometric radiography unit.
2. There is no difference between the calculated magnification indexes of separate linear measurements from lateral cephalometric images taken at the same distance from the x-ray source within the same lateral cephalometric radiography unit.
3. There is no difference between the calculated magnification indexes from lateral cephalometric images taken at the same distance from the x-ray source in scanning and static lateral cephalometric radiography units made by the same manufacturer.
4. There is no difference between angular measurements in lateral cephalometric images from scanning and static lateral cephalometric radiography units made by the same manufacturer.
5. There is no distortion in images from lateral cephalometric radiography units.

Paper #2

1. There is no difference between linear measurements from lateral cephalometric images obtained from scanning and static lateral cephalometric radiography units made by the same manufacturer.
2. There is no difference in angular measurements between lateral cephalometric images obtained from scanning and static lateral cephalometric radiography units made by the same manufacturer.
3. There is no clinically significant difference in linear and angular measurements between lateral cephalometric images obtained from scanning and static lateral cephalometric radiography units made by the same manufacturer.

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Chapter 2 - The Accuracy of Scanning CCD Cephalometric Units in Comparison to Static Cephalometric Units Using a Phantom (Research Paper 1)

2.1 Introduction

Cephalometry is an important tool in orthodontic diagnosis, treatment planning, evaluation of treatment results, and prediction of growth. In the past ten years digital radiography has become more available and is used more regularly in dental offices because of many benefits it offers over traditional film based radiography. Digital radiography allows immediate image acquisition, computer archiving, computer aided cephalometric analysis, radiation dose reduction, and the environmental and cost benefit of no processing chemicals.[1,2]

Radiographic images can be produced by an analog process or by a digital process. A conventional film image is created by the interaction of ionizing radiation and x-ray film. A digital image is created when the diagnostic information is presented in a digital format rather than in conventional film.[3] The digital image is made up of a large number of discrete picture elements (pixels). Location is identified by row and column coordinates within the image matrix.[4] Digital mages can be acquired by means of a photo-stimulated storage phosphor plate (PSP), charge coupled device (CCD) receptors, or digitization of radiographic films with computer scanners. [5,6]

Currently, there are multiple varieties of imaging projections for cephalometric radiography. Traditional lateral cephalometric imaging uses a pyramid shaped x-ray beam that is applied in a static manner (Figure 2.1). For direct digital cephalometry there are two modes of image acquisition, static and scanning. Of the scanning units, there is horizontal and vertical scanning, that produce significantly different projection geometry when compared with traditional film based cephalometric units (Figure 2.1).[7,8] The scanning CCD (charge coupled device) cephalometric machines have fan shaped x-ray beams that scan vertically or horizontally.

The limitation of landmark identification on lateral cephalometric radiographs has been the source of many studies because measurements are based on the accuracy of their placement. [6,9-14] The angular and linear measurements from these landmarks are compared to collected norm measurements for diagnosis. Computer programs have been developed with cephalometric analyses that are automatically calculated once landmarks have been selected.[15,16] The magnification of the radiograph must be known in order for the program to determine the measurements properly. Typically the magnification is determined using a ruler that runs vertically on the radiograph. If the magnification factors are not the same vertically and horizontally distortion is created that is unaccounted for in the final analysis.

Correction of measurement errors in cephalometrics used in orthodontics has been a topic of discussion since Broadbent introduced his paper in 1931 "A New X-ray Technique and Its Application in Orthodontia".[17] He describes taking a lateral cephalogram and how to correct for magnification error created by non-parallel x-ray beams by knowing "the predetermined target distance, five feet, and film distance". The positioning of patients in relation to the film has not changed significantly since.[3] A patient is still positioned 5 feet from the x-ray tube and the central ray of the lateral tube passes down the length of the ear posts along their superior surfaces and meets the midsagittal plane and the film surfaces at right angles as was described by Brodie in 1949 .[18] The inherent distortion found in cephalometric radiographs has been accepted because it is a two dimensional representation of a three dimensional object. Due to the pyramidal shape of the x-ray beam the right and left sides can not be superimposed exactly. The structures on the side closest to the image receptor are magnified less than the opposite side.[4] (Figure 2.2)

The aim of this study was to use a radiographic phantom of known dimensions to evaluate the measurement of magnification and distortion on lateral cephalometric images, at specific distances from the x-ray source, produced by scanning CCD and static cephalometric radiograph units. The images produced were two dimensional images of a two dimensional sheet, eliminating the distortion produced by creating a two dimensional image of a three dimensional object. For this study the static units are considered the gold standard because all current norms for cephalometric measurements are based on this type of x-ray beam geometry.

2.2 Materials and Methods

2.2.1 Phantom Test Device Design

The custom designed phantom was fabricated in the University of Alberta Medicine and Dentistry Workshop. The phantom was fabricated out of acrylic with the dimensions of 21 cm x 21 cm x 15 cm internally. A 21 cm x 21 cm x 0.5 cm sheet of acrylic was prepared using a Dekel Maho (DMG Canada Inc., Mississauga, ON) milling machine with a digital read out calibrated at 10 mm increments. Radiopaque markers consisting of 1.58 mm steel balls (Small Parts, Inc. Miami Lakes, FL) were placed 1 cm on center from each other horizontally and vertically in concentric rectangles. Slots, 0.5 cm x 0.5 cm were created for precise positioning of the sheet within the box at specific increments. Three positions, labeled Slot 1, Slot 4, and Slot 7, were chosen at 6 cm distances from each other, to approximately represent lateral sides of a skull and the midsagittal plane. Slot 7 was closest to the image receptor. The true distance measurements were confirmed using the Coordinate Measuring Machine (Starett Corporation, Athol, MA). A camera tripod (Opus, Ontario, CA) was attached to the base of the box with the aid of a Denar (Waterpik Technologies, Ft. Collins, CO) mounting plate fixed with cold cure acrylic to the base of the phantom. (Figure 2.3)

2.2.2 Cephalometric Radiographs

Lateral cephalometric radiographs were taken of the phantom on four separate machines:

Unit 1: Orthoceph OC100 D (General Electric, Tuusula, Finland)
Unit 2: Orthoceph OC100 (General Electric, Tuusula, Finland)
Unit 3: Orthophos DS Ceph (Sirona Dental Systems, Bensheim,Germany)
Unit 4: Orthophos CD Ceph (Sirona Dental Systems, Bensheim,Germany)

For each cephalometric radiography unit the objective was to position the phantom to simulate the desired position of the patient's head in the cephalometric unit. For all units positioning involved the centering of the phantom to the middle of the box with the base of the box parallel to the floor, and the ear rods placed into the centered holes on the lateral aspects of the box. (Figure 2.4) Forty-five images were produced from each machine. The phantom was positioned fifteen separate times for each of the three depths of the steel ball marked sheet into each of the four different cephalometric radiograph units and exposed. Test exposures were made on each unit to establish kV, mA, and time setting that provided the images with sufficient density and contrast for future landmark identification.

The Orthoceph OC100 D is a horizontally scanning direct digital machine which has a CCD receptor that is coupled with a V-shaped x-ray beam. The resulting image has a pixel matrix of 2052 x 2348, with a resolution of 5lp/mm. The exposure parameters were 73 kV, 15 mA and 15.8 seconds.

The Orthoceph OC100 from GE is a conventional static film based unit, which exposes the radiographic film in static manner using a pyramid-shaped x-ray beam. The exposure parameters were 77 kV, 14 mA, and 0.5 seconds. The radiographs were taken on Fuji HR - S30, 8 x 10 inch film (Fujifilm, Roseville, IL). Both GE units have focal spot sizes of 0.35 mm x 0.5 mm. Each machine was certified for use.

The Orthophos DS Ceph from Sirona is a vertically scanning direct digital machine, which has a CCD receptor that is placed horizontally and coupled relative to the fan-shaped horizontally collimated x-ray beam. The resulting image has a pixel matrix of 2052 x 2348. The exposure parameters were 73 kV, 15 mA and 15.8 seconds.

The Orthophos CD from Sirona Dental systems conventional static unit, which has a pyramid-shaped X-ray beam. The exposure settings were 77 kV, 14mA, and 0.5 seconds The Orthophos CD used in this study replaced the x-ray film with an 8 x10 inch photo-stimulated storage phosphor plate (PSP) from DenOptix (Gendex, Lake Zurich, IL). The PSP was processed after every image using a DenOptix laser scanner (Gendex, Lake Zurich, IL) at a resolution of 150 dpi. Both of the Sirona units have a focal spot size of 0.5 mm x 0.5 mm.

2.2.3 Radiographic Distance Measurements

Radiographs from the film-based OC100 were scanned at a resolution of 200 dpi with an Epson Expression 1680 (Epson America, Long Beach, CA). Once digitized, images from the four cephalometric radiograph units were saved as tiff files on a Toshiba Satellite A20 PC (Toshiba, New York, NY). All radiographs were digitized and calibrated for pixels/mm prior to measurement using Image J software (NIH, Bethesda, MD), a public domain Java processing program. The x and y coordinates, linear measurements, and angular measurements were all measured separately. All measurements were made twice at intervals separated by a minimum of two weeks.

Four of the marked points were labeled, A, B, C, and D. (Figure 2.5) Six measurements were recorded in millimeters from lines AB, AC, AD, BC, BD, and CD. Lines AB, AC, and AD were equal in length and lines BC and CD were equal in length. Line BC represents true horizontal and CD represents true vertical. Nine measurements were recorded in degrees from angles ABC, ACD, ADC, BDC, BCA, DBC, CAD, BAC, and BCD. Angles ABC, ACD, ADC, BDC, BCA, DBC, were equal and angles CAD, BAC, BCD were equal. The data generated was entered into an Excel (Microsoft, Redmond, WA) spreadsheet. The average radiographic distance measurements are reported in Table 2.1.

2.2.4 Magnification Factor and Distortion Index

The magnification factor is defined as the ratio of the radiographic distance to the true distance. The magnification factor was determined using the formula:

$$\text{Magnificat ion Factor} = \frac{\text{Radiograph ic Display Distance (mm)}}{\text{True Distance (mm)}}$$

The magnification factor was determined for all linear measurements.

The distortion index is the ratio of the vertical magnification factor to the horizontal magnification factor. Once the magnification factors are determined then the distortion index can be determined by using the formula:

$$\text{Distortion Index} = \frac{\text{Vertical Magnification Factor}}{\text{Horizontal Magnification Factor}}$$

A distortion index equal to one indicates that there is no distortion and the proportions of the object being imaged are being depicted correctly. The distortion index was determined using the magnification factor of line CD representing true vertical, divided by the magnification factor of line BC representing true horizontal.

2.2.5 The Error of the Method and Statistical Analysis

All phantom positioning and image measurements were undertaken by the principal investigator. The total error of each image measurement was a combination of repeated phantom positioning in the cephalometric unit and the digitization error. For each unit the error in the linear measurements ranged from 0.04 mm to 0.12 mm (Orthoceph OC100 D), 0.07 mm to 0.19 mm (Orthoceph OC100), 0.10 mm to 0.22 mm (Orthophos DS Ceph), 0.05 mm to 0.16 mm (Orthophos CD). For each unit the angular measurements the error ranged from 0.00° to 0.13° (Orthoceph OC100 D), 0.00° to 0.16° (Orthoceph OC100), 0.01° to 0.26° (Orthophos DS Ceph), 0.00° to 0.16° (Orthophos CD).

2.2.6 Statistical Analysis

A repeated measure ANOVA test was performed together with post-hoc Bonferroni pairwise comparison tests to compare magnifications and distortions within the same slots between machines of the same manufacturer. A distortion index with a value equal to one indicates that there is no distortion and the proportions of the object being imaged are depicted correctly. The same analysis was performed to compare 45°

and 90° angular measurements between machines of the same manufacturer. Significance levels of less than 5% were considered to be statistically significant.

2.3 Results

The mean and standard deviation values of the angular measurements are presented in Table 2.2. The Orthoceph OC100 D measurement of the angles with true measurements of 90° ranged from 89.59° to 89.84° and measurement of the angles with true measurements of 45° ranged from 44.66° to 44.92° across all slots. The Orthoceph OC100 measurement of the angles with true measurements of 90° ranged from 88.51° to 90.83° and measurement of the angles with true measurements of 45° ranged from 44.26° to 45.57° across all slots. The Orthophos DS Ceph measurement of the angles with true measurements of 90° ranged from 87.23° to 92.64° and measurement of the angles with true measurements of 45° ranged from 43.50° to 46.44° across all slots. The Orthophos CD measurement of the angles with true measurements of 90° ranged from 89.83° to 90.02° and measurement of the angles with true measurements of 45° ranged from 44.88° to 45.19° across all slots.

Mean and standard deviation values of the calculated magnification factors for the phantom measurements are presented in Table 2.3. The average magnification for Orthoceph OC100 D in Slot 1 was 1.05, Slot 4 was 1.01, and Slot 7 was 0.97. The average magnification for Orthoceph OC100 in Slot 1 ranged from 1.19 to 1.21, Slot 4 ranged from 1.14 to 1.16, and Slot 7 ranged from 1.10 to 1.11. The average magnification for Orthophos DS Ceph in Slot 1 ranged from 1.10 to 1.15, Slot 4 ranged from 1.10 to 1.11, and Slot 7 ranged from 1.06 to 1.09. The average magnification for Orthophos CD in Slot 1 ranged from 1.18 to 1.17, Slot 4 ranged from 1.12 to 1.13, and

Slot 7 ranged from 1.06 to 1.09.

Repeated measures ANOVA of the magnification factors and angular measurements are presented in Table 2.4 and Table 2.5 respectively. Statistically significant differences were found between all of the magnification factors except AB and CD in Slot 7 between Orthophos DS Ceph and Orthophos CD. Statistically significant differences were found between all of the angles except angle BCD in all Slots between Orthoceph OC100 D and Orthoceph OC100 and angles ADC and BDC in Slot 4 between Orthophos DS Ceph and Orthophos CD.

Mean and standard deviation values of the calculated distortion indices are presented in Table 2.6. Both Orthoceph OC100 D and Orthophos CD had distortion indices of 1.00 indicating that the vertical and horizontal magnification factors were equal. The Orthoceph OC100 had a distortion index of 1.02 across all slots indicating that the vertical magnification was greater than the horizontal magnification. The Orthophos DS Ceph had a distortion index of 0.96 and 0.99 for slots 1 and 4 respectively indicating that the horizontal magnification was greater than the vertical magnification, in slot 7 the distortion index was 1.03 indicating that the vertical magnification was greater than the horizontal magnification.

2.3 Discussion

The dimensional accuracy of a lateral cephalometric image is determined by both the horizontal and vertical magnification. The inherent magnification seen on a lateral cephalometric image is dependant upon the position of an object between the x-ray source and the film. Ideally the amount of magnification produced from the x-ray beam geometry would be equal vertically and horizontally. The Orthoceph OC100 D, scanning CCD machine, operates with a vertically collimated x-ray beam that is moved horizontally through the whole exposure region and the Orthophos DS Ceph machine operates with a horizontally collimated x-ray beam that is moved vertically through the whole exposure region This is a significantly different x-ray beam geometry than their manufacturer's conventional counterparts, the Orthoceph OC100 and Orthophos CD respectively, which have a pyramidal shaped beam applied in a static manner.

The inherent distortion found in cephalometric radiographs has been accepted in orthodontics because the image produced is a two dimensional representation of a three dimensional object. Due to the pyramidal shape of the x-ray beam, produced from conventional machines, the right and left sides cannot be superimposed exactly. The structures on the side closest to the image receptor are magnified less than the opposite side.[4] In this study, the use of a phantom allowed evaluation of the effect of x-ray beam geometry on a two dimensional object that could be moved towards and away from the image receptor without superimposition.

The results of this study revealed that the Orthoceph OC 100D and the Orthophos CD both had distortion indices of 1 across all slots, indicating that the horizontal and vertical magnification factors were equal (Figure 2.6 and Figure 2.7). For the Orthoceph OC 100D, the horizontally scanning x-ray beam did not affect the vertical magnification factor. The Orthoceph OC 100 had a distortion index of 1.02 across all slots, indicating that the vertical magnification was greater than the horizontal magnification by the same magnification factor at all distances. The distortion indices for the Orthophos DS are different at every slot, indicating that the vertical and horizontal magnification factors do not vary in the same manner with respect to the distance from the x-ray source. The mean magnification factors for Orthophos DS show that the vertical measurement (line CD) maintains relatively the same magnification factor across all slots, while the horizontal magnification factor (line BC) increases from Slot 7 to Slot 1 (Figure 2.8 and 2.9). An increase in magnification factor is expected as the object moves away from the image receptor. Maintenance of the vertical magnification factor is unique to this machine. For the Orthophos DS, the vertical scanning x-ray beam does affect the vertical magnification.

In the Schulze[13] study, using a dry human skull, they reported that the effective magnification was larger for the digital images (x, 13%; y, 12%) when comparing the Orthophos DS to the Orthophos CD. The reported average magnification factors for the conventional unit were 1.09 along the x-axis and 1.09 along the y-axis; for the CCD unit the magnification factor was 1.25 along the x-axis and 1.22 along the y-axis. The results of this present study found the average magnification across all slots for the Orthophos CD was minimally larger than the Orthophos DS (x, 11.3% and 11%; y, 11.3% and 11% respectively). The average magnification factors for the conventional unit were 1.13 along the x-axis and 1.13 along the y-axis; for the CCD unit the magnification factor was 1.10 along the x-axis and 1.10 along the y-axis. The opposite was found for the GE units. The average magnification across all slots for the OC100 was larger than the OC100 D (x, 11.4% and 10.1%; y, 11.6% and 10.1% respectively). The average magnification factors for the conventional unit were 1.14 along the x-axis and 1.16 along the y-axis; for the CCD unit the magnification factor was 1.01 along the x-axis and 1.01 along the y-axis.

The differences in the vertical and horizontal magnification factors leading to distortion are also demonstrated in the angular measurements between machines, because angular measurements are not affected by magnification if it is equal horizontally and vertically. For the GE machines the only angles that did not demonstrate a significant difference were angles BCD across all slots. This is because it is the only angle that does not combine the horizontal and vertical magnification in its measurement. For the Sirona machines the only angles that did not demonstrate a statistically significant difference were found in slot 4. In slot 4 the distortion indices were 0.99 and 1.00 for Orthophos DS and the Orthophos CD respectively, therefore the angular measurements should be very close to the same except for measurement error. Although statistically significant differences in magnification factors, angular measurements, and distortion indices were found for all the radiographic units, many of these differences are small. It is important to determine whether these differences have any clinical significance. For example the greatest angular difference for the GE machines was 1.13° and for the Sirona machines it was 2.6°. The greatest difference in magnification factors was 0.16 and 0.08 for the GE and Sirona machines respectively. Clinically, it is doubtful the angular difference would be relevant. The magnification factor could become clinically relevant in millimeter measurements over longer distances. If a time one to time two measurement is being compared for growth the resulting measurement would not be accurate.

The results of this study can only be applied to the particular models of cephalometric radiography units utilized. In addition the use of a phantom does not allow for extrapolation of the results of this study to the population in general.

2.4 Conclusion

The following conclusions can be drawn from this study:

1. Statistically significant variation exists between the calculated magnification indexes of separate linear measurements from lateral cephalometric images taken at the same distance from the x-ray source within the same lateral cephalometric radiography unit.
2. Statistically significant variation between the calculated magnification indexes of separate linear measurements from lateral cephalometric images taken at the decreasing distances from the x-ray source within the same lateral cephalometric radiography unit.
3. Statistically significant variation between the calculated magnification indexes from lateral cephalometric images taken at the same distance from the x-ray source in scanning and static lateral cephalometric radiography units made by the same manufacturer.
4. Statistically significant variation between angular measurements in lateral cephalometric images from scanning and static lateral cephalometric radiography units made by the same manufacturer, except angle BCD in the images from GE lateral cephalometric radiography units.
5. Distortion was found in images from OC 100 and Orthophos DS lateral cephalometric radiography units.

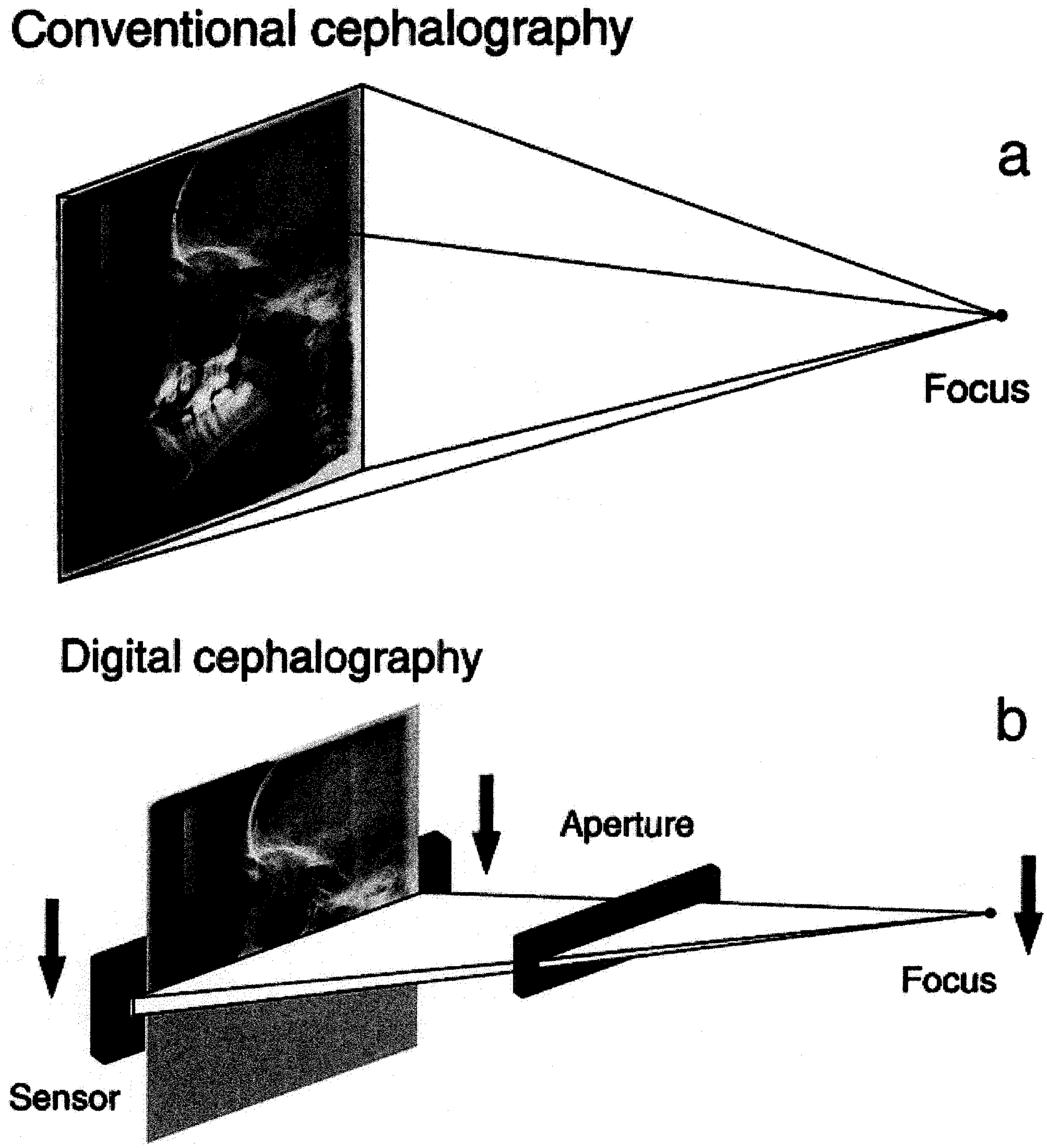


Figure 2.1 Static vs. Vertical Scanning X-ray Beam Geometry
(From Visser H, Rodig T, Hermann KP. Dose reduction by direct-digital cephalometric radiography. Angle Orthod 2001;71:159-163.)

Figure 2.2 Projection of X-ray Beam

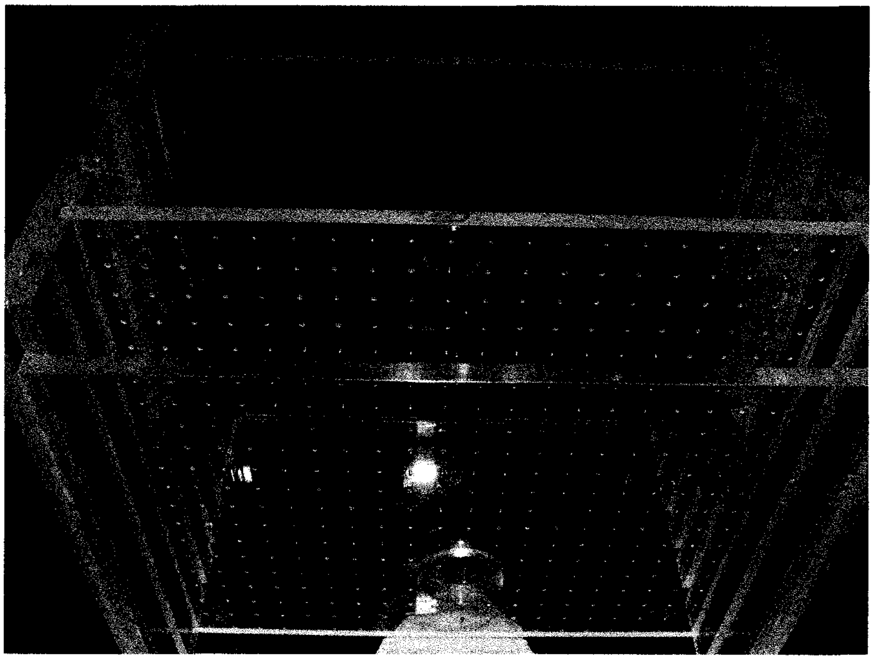


Figure 2.3 Phantom

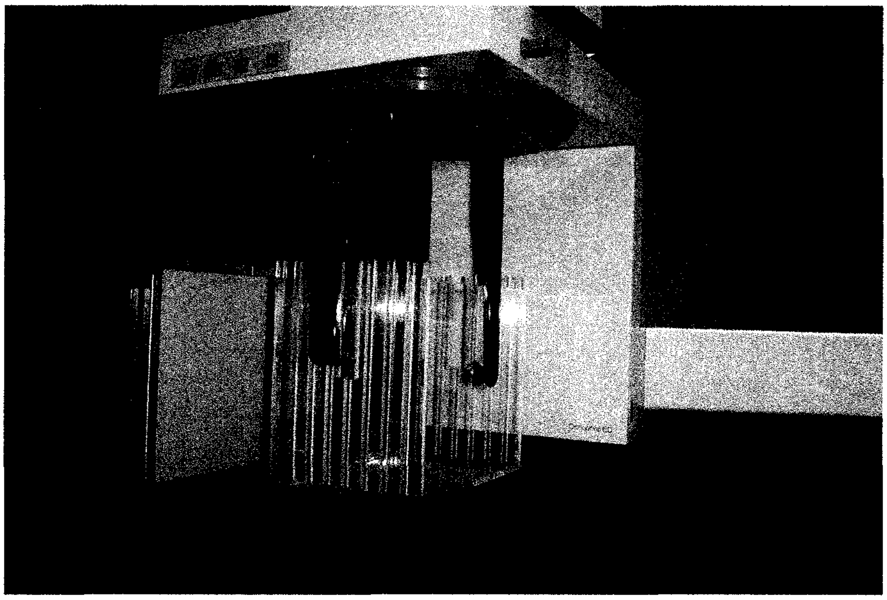


Figure 2.4 Phantom Positioned for Cephalometric Imaging

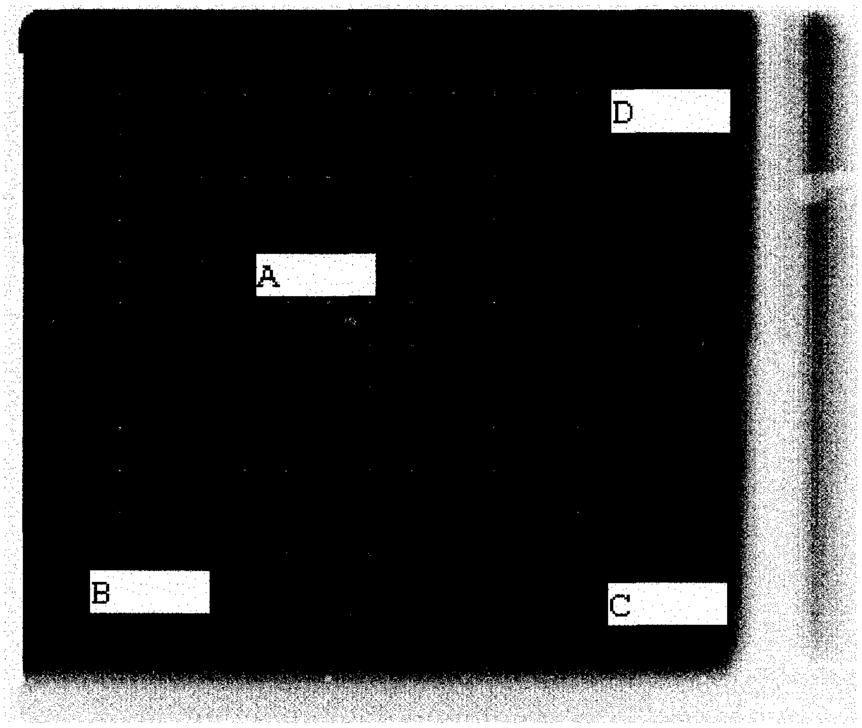
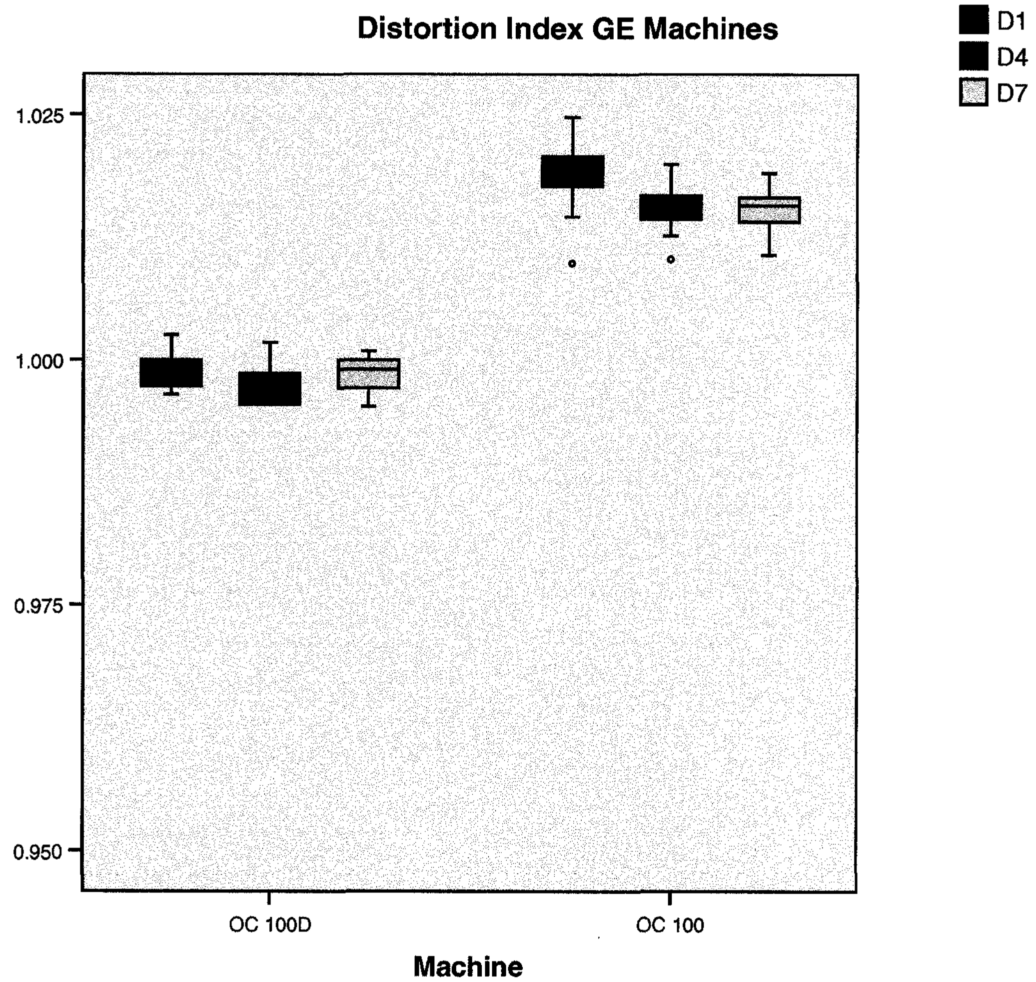


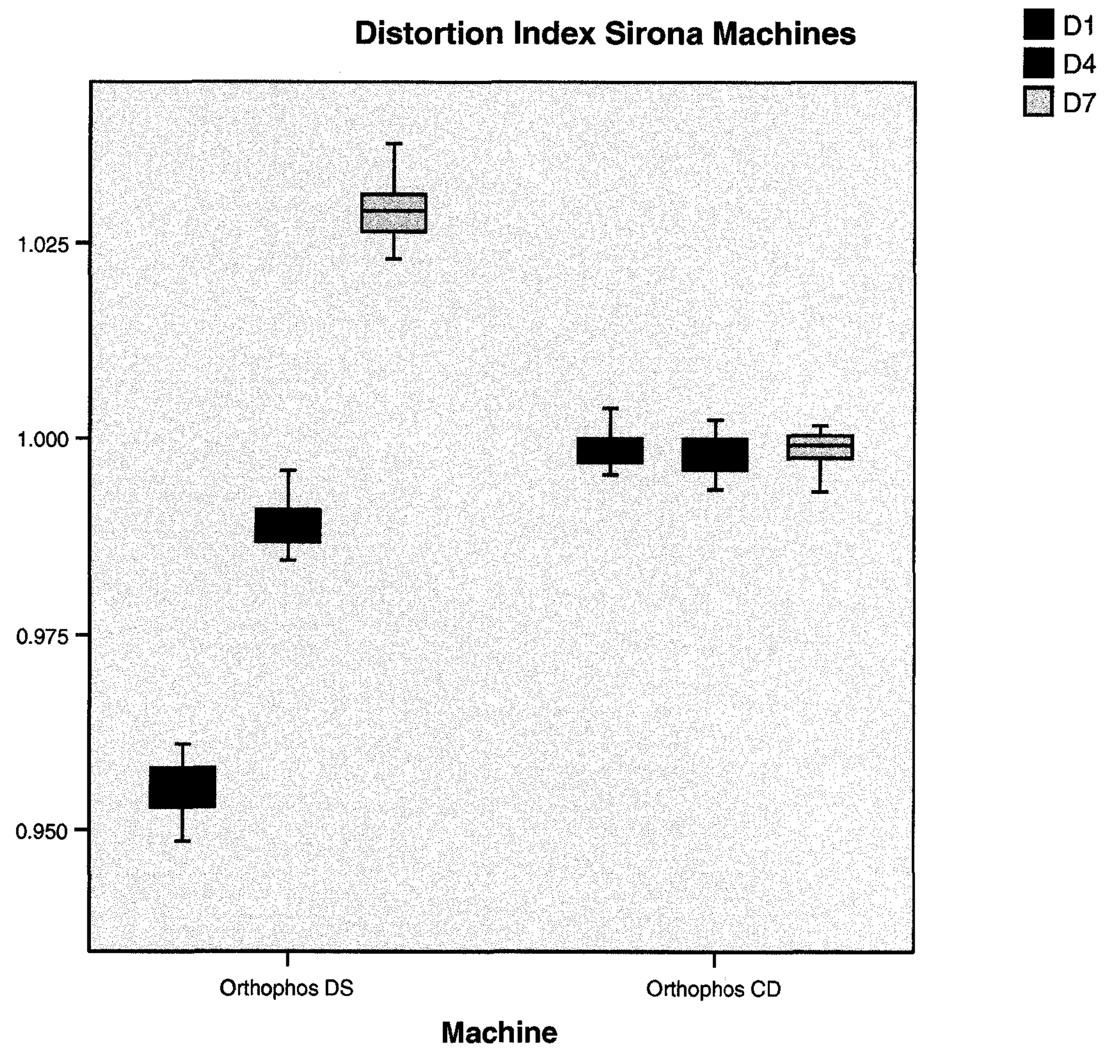
Figure 2.5 Labeled Phantom Image



*box contains middle 50% of the data
vertical lines represent minimum and maximum data vaules
o represent possible outliers

1=Slot 1
4=Slot 4
7=Slot 7

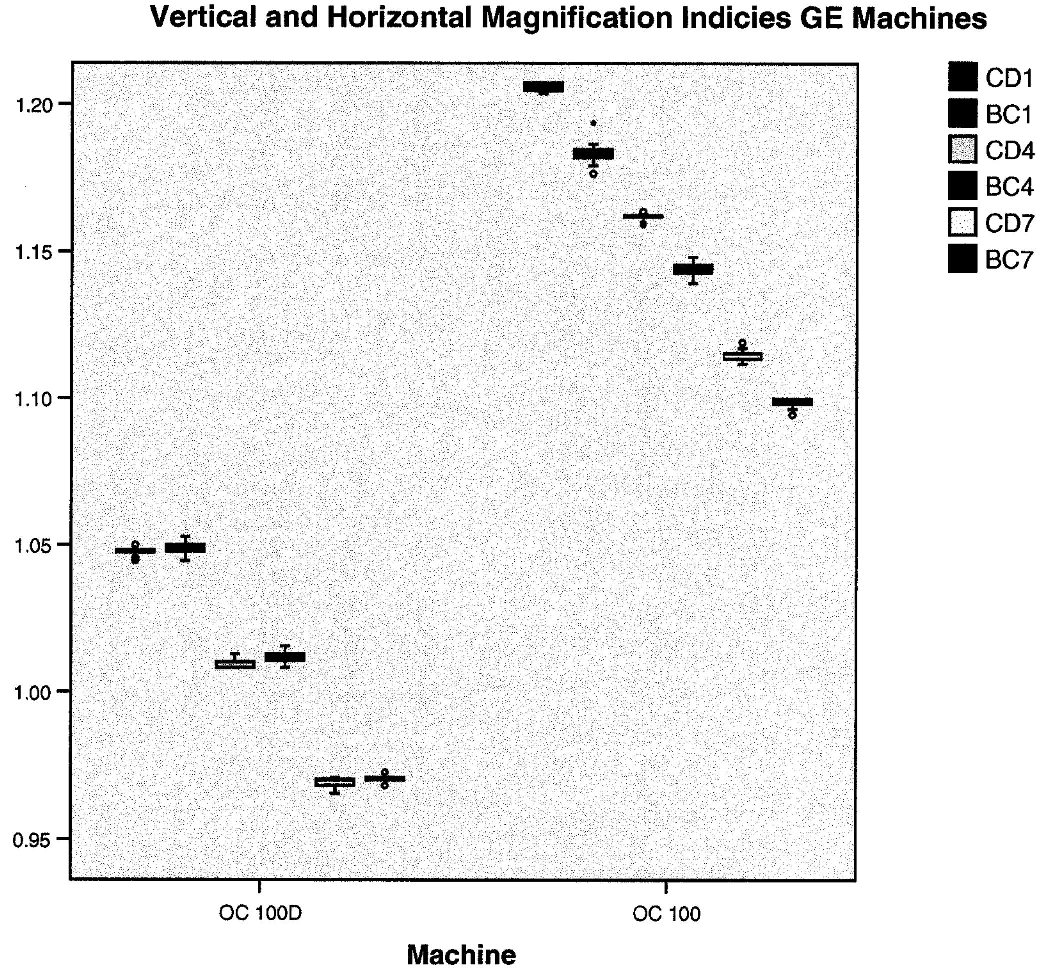
Figure 2.6 Boxplot of calculated distortion indices GE Machines*



*box contains middle 50% of the data
vertical lines represent minimum and maximum data vaules

1=Slot 1
4=Slot 4
7=Slot 7

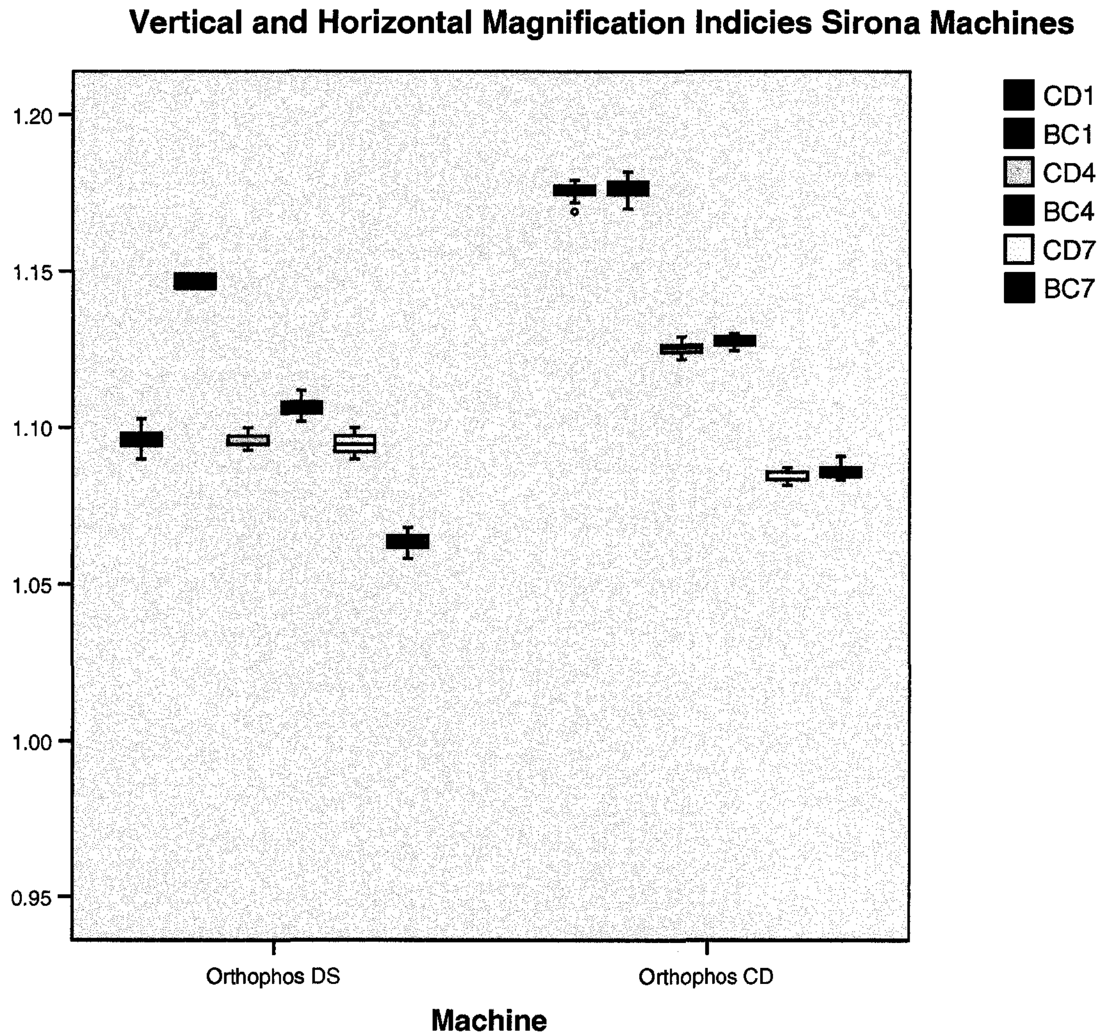
Figure 2.7 Boxplot of calculated distortion indices Sirona Machines*



*box contains middle 50% of the data
vertical lines represent minimum and maximum data vaules
o represent possible outliers

CD = vertical magnification factor
BC = horizontal magnification factor
1 = Slot 1
4 = Slot 4
7 = Slot 7

Figure 2.8 Boxplot of calculated vertical and horizontal magnification indices GE*



*box contains middle 50% of the data
vertical lines represent minimum and maximum data vaules
o represent possible outliers

CD = vertical magnification factor
BC = horizontal magnification factor
1 = Slot 1
4 = Slot 4
7 = Slot 7

Figure 2.9 Boxplot of calculated vertical and horizontal magnification indices Sirona*

Table 2.1 Mean and standard deviation values for distance measurements (in mm)

		TRUE		OC100 D		OC100		OrthophosDS		OrthophosCD	
Line	Slot	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
AB	1	77.81	0.04	81.60	0.18	92.74	0.38	87.60	0.39	91.59	0.03
AC	1	77.82	0.05	81.48	0.12	92.81	0.26	86.98	0.28	91.50	0.01
AD	1	77.79	0.05	81.45	0.16	92.65	0.29	86.88	0.32	91.20	0.02
BC	1	109.99	0.06	115.37	0.23	130.15	0.42	126.16	0.23	129.44	0.03
CD	1	110.03	0.06	115.24	0.19	132.63	0.16	120.52	0.41	129.25	0.03
BD	1	155.60	0.05	162.98	0.28	185.39	0.20	174.53	0.3	182.62	0.04
AB	4	77.81	0.04	79.04	0.19	89.96	0.40	86.08	0.29	87.73	0.03
AC	4	77.82	0.05	78.77	0.16	89.57	0.17	85.36	0.22	87.60	0.02
AD	4	77.79	0.05	78.56	0.14	89.32	0.27	85.41	0.24	87.37	0.03
BC	4	109.99	0.06	111.30	0.22	125.86	0.27	121.74	0.29	124.04	0.02
CD	4	110.03	0.06	111.05	0.15	127.80	0.15	120.50	0.22	123.82	0.02
BD	4	155.60	0.05	157.18	0.19	179.09	0.34	171.40	0.31	174.82	0.03
AB	7	77.81	0.04	75.54	0.20	86.20	0.30	84.26	0.32	84.21	0.02
AC	7	77.82	0.05	75.44	0.26	86.11	0.25	83.36	0.4	84.43	0.02
AD	7	77.79	0.05	75.28	0.16	85.76	0.24	84.07	0.26	84.42	0.03
BC	7	109.99	0.06	106.74	0.14	120.81	0.18	116.97	0.28	119.45	0.02
CD	7	110.03	0.06	106.60	0.18	122.65	0.22	120.42	0.35	119.30	0.02
BD	7	155.60	0.05	150.81	0.19	172.04	0.28	168.25	0.38	168.40	0.04

Table 2.2 Mean and standard deviation values for angular measurements (in degrees)

		TRUE		OC100 D		OC100		OrthophosDS		OrthophosCD	
Angle	**Slot**	**Mean**	**S.D.**	**Mean**	**S.D.**	**Mean**	**S.D.**	**Mean**	**S.D.**	**Mean**	**S.D.**
BAC	**1**	90.05	0.08	89.76	0.10	88.51	0.19	92.64	0.15	90.02	0.16
CAD	**1**	90.04	0.08	89.61	0.16	90.83	0.17	87.23	0.27	89.83	0.16
BCD	**1**	90.01	0.07	89.84	0.10	89.83	0.12	90.29	0.17	89.95	0.10
ABC	**1**	44.97	0.05	44.84	0.11	45.33	0.10	43.53	0.16	45.01	0.08
DBC	**1**	44.97	0.07	44.84	0.07	45.33	0.10	43.50	0.12	44.96	0.11
BCA	**1**	45.03	0.10	44.76	0.12	45.33	0.14	43.90	0.13	44.97	0.11
ACD	**1**	45.02	0.08	44.69	0.12	44.26	0.12	46.44	0.14	45.04	0.12
ADC	**1**	44.99	0.10	44.84	0.11	44.32	0.13	46.09	0.40	45.19	0.07
BDC	**1**	90.05	0.08	44.84	0.10	44.37	0.08	46.10	0.19	45.10	0.07
BAC	**4**	90.04	0.08	89.59	0.17	88.63	0.15	90.51	0.21	89.90	0.17
CAD	**4**	90.01	0.07	89.76	0.14	90.68	0.18	89.41	0.19	89.84	0.19
BCD	**4**	44.97	0.05	89.83	0.11	89.63	0.22	90.24	0.15	89.95	0.20
ABC	**4**	44.97	0.07	44.67	0.12	45.57	0.07	44.59	0.13	45.11	0.11
DBC	**4**	45.03	0.10	44.80	0.09	45.29	0.12	44.57	0.08	45.00	0.11
BCA	**4**	45.02	0.08	44.83	0.09	44.85	0.24	44.66	0.14	44.88	0.15
ACD	**4**	44.99	0.10	44.83	0.09	44.13	0.17	45.55	0.12	45.09	0.13
ADC	**4**	90.05	0.08	44.91	0.12	44.44	0.14	45.15	0.19	45.18	0.13
BDC	**4**	90.04	0.08	44.92	0.07	44.43	0.11	45.18	0.15	45.14	0.12
BAC	**7**	90.05	0.08	89.83	0.16	88.66	0.20	88.34	0.15	89.90	0.19
CAD	**7**	90.04	0.08	89.83	0.12	90.72	0.11	91.77	0.21	89.90	0.20
BCD	**7**	90.01	0.07	89.83	0.08	89.81	0.10	90.18	0.11	89.94	0.12
ABC	**7**	44.97	0.05	44.66	0.14	45.35	0.09	45.63	0.13	45.10	0.13
DBC	**7**	44.97	0.07	44.83	0.05	45.23	0.08	45.71	0.11	45.03	0.10
BCA	**7**	45.03	0.10	44.91	0.14	45.27	0.11	45.98	0.21	45.00	0.18
ACD	**7**	45.02	0.08	44.66	0.13	44.37	0.09	44.33	0.11	44.95	0.13
ADC	**7**	44.99	0.10	44.83	0.10	44.47	0.07	43.89	0.25	45.15	0.15
BDC	**7**	90.05	0.08	44.92	0.06	44.46	0.07	43.97	0.11	45.07	0.11

Table 2.3 Mean and standard deviation values for the calculated magnification factor*

		OC100 D		OC100		OrthophosDS		OrthophosCD	
Line	**Slot**	**Mean**	**S.D.**	**Mean**	**S.D.**	**Mean**	**S.D.**	**Mean**	**S.D.**
AB	**1**	1.05	0.003	1.19	0.005	1.13	0.005	1.18	0.004
AC	**1**	1.05	0.002	1.19	0.003	1.12	0.003	1.18	0.002
AD	**1**	1.05	0.002	1.19	0.004	1.12	0.004	1.17	0.003
BC	**1**	1.05	0.002	1.18	0.004	1.15	0.001	1.18	0.003
CD	**1**	1.05	0.002	1.21	0.001	1.10	0.002	1.18	0.003
BD	**1**	1.05	0.002	1.19	0.002	1.12	0.004	1.17	0.003
AB	**4**	1.02	0.003	1.16	0.005	1.11	0.004	1.13	0.004
AC	**4**	1.01	0.002	1.15	0.002	1.10	0.003	1.13	0.002
AD	**4**	1.01	0.002	1.15	0.003	1.10	0.003	1.12	0.004
BC	**4**	1.01	0.002	1.14	0.002	1.11	0.003	1.13	0.002
CD	**4**	1.01	0.002	1.16	0.001	1.10	0.002	1.13	0.002
BD	**4**	1.01	0.003	1.15	0.002	1.10	0.002	1.12	0.002
AB	**7**	0.97	0.003	1.11	0.004	1.08	0.004	1.08	0.002
AC	**7**	0.97	0.002	1.11	0.003	1.07	0.004	1.09	0.003
AD	**7**	0.97	0.001	1.10	0.002	1.08	0.003	1.08	0.003
BC	**7**	0.97	0.001	1.10	0.002	1.06	0.003	1.09	0.002
CD	**7**	0.97	0.001	1.11	0.002	1.09	0.002	1.08	0.002
BD	**7**	0.97	0.002	1.11	0.002	1.08	0.003	1.08	0.002

*Magnification factor = radiographic distance/actual distance

Table 2.4 Repeated measures ANOVA of the calculated magnification factors *

		Magnification Difference			
		OC100D-OC100		OrthophosDS-OrthophosCD	
Line	**Slot**	**Mean Difference**	**P-value**	**Mean Difference**	**P-value**
AB	**1**	-0.143	0.000*	-0.051	0.000*
AC	**1**	-0.146	0.000*	-0.058	0.000*
AD	**1**	-0.144	0.000*	-0.056	0.000*
BC	**1**	-0.134	0.000*	-0.030	0.000*
CD	**1**	-0.158	0.000*	-0.080	0.000*
BD	**1**	-0.144	0.000*	-0.052	0.000*
AB	**4**	-0.140	0.000*	-0.022	0.000*
AC	**4**	-0.139	0.000*	-0.029	0.000*
AD	**4**	-0.138	0.000*	-0.025	0.000*
BC	**4**	-0.132	0.000*	-0.021	0.000*
CD	**4**	-0.152	0.000*	-0.030	0.000*
BD	**4**	-0.141	0.000*	-0.022	0.000*
AB	**7**	-0.137	0.000*	0.001	0.677
AC	**7**	-0.137	0.000*	-0.014	0.000*
AD	**7**	-0.135	0.000*	-0.003	0.040*
BC	**7**	-0.128	0.000*	-0.022	0.000*
CD	**7**	-0.137	0.000*	0.010	0.243
BD	**7**	-0.146	0.000*	-0.001	0.000*

Mean difference = magnification of distance OC100D-OC100
Mean difference = magnification of distance OrthophosDS-OrthophosCD
* A P-value of less than 0.050 is considered statistically significant

Table 2.5 Repeated measures ANOVA of angular measurements*

		Degree Difference			
		OC100D-OC100		OrthophosDS-OrthophosCD	
Angle	Slot	Mean Difference	P-value	Mean Difference	P-value
BAC	1	1.133	0.000*	2.621	0.000*
CAD	1	-1.023	0.000*	-2.596	0.000*
BCD	1	-0.026	0.516	0.343	0.000*
ABC	1	-0.627	0.000*	-1.480	0.000*
DBC	1	-0.536	0.000*	-1.462	0.000*
BCA	1	-0.514	0.000*	-1.062	0.000*
ACD	1	0.442	0.000*	1.398	0.000*
ADC	1	0.449	0.000*	0.906	0.000*
BDC	1	0.546	0.000*	1.005	0.000*
BAC	4	1.111	0.000*	0.608	0.000*
CAD	4	-1.078	0.000*	-0.429	0.000*
BCD	4	0.111	0.091	0.298	0.000*
ABC	4	-0.704	0.000*	-0.525	0.000*
DBC	4	-0.600	0.000*	-0.434	0.000*
BCA	4	-0.443	0.000*	-0.217	0.000*
ACD	4	0.584	0.000*	0.465	0.000*
ADC	4	0.435	0.000*	-0.034	0.578
BDC	4	0.450	0.000*	0.042	0.416
BAC	7	1.012	0.000*	-1.556	0.000*
CAD	7	-0.828	0.000*	1.864	0.000*
BCD	7	0.047	0.180	0.248	0.000*
ABC	7	-0.523	0.000*	0.533	0.000*
DBC	7	-0.500	0.000*	0.679	0.000*
BCA	7	-0.423	0.000*	0.988	0.000*
ACD	7	0.412	0.000*	-0.615	0.000*
ADC	7	0.397	0.000*	-1.257	0.000*
BDC	7	0.428	0.000*	-1.104	0.000*

Mean difference = angular measurement of CCD unit – Static unit

* A P-value of less than 0.050 is considered statistically significant

Table 2.6 Mean and standard deviation values for distortion index*

	OC100 D		OC100		Orthophos DS		Orthophos CD	
Slot	**Mean**	**S.D.**	**Mean**	**S.D.**	**Mean**	**S.D.**	**Mean**	**S.D.**
1	1.00	0.002	1.02	0.004	0.96	0.004	1.00	0.004
4	1.00	0.002	1.02	0.002	0.99	0.003	1.00	0.003
7	1.00	0.002	1.02	0.002	1.03	0.004	1.00	0.002

Distortion Index = vertical magnification factor/horizontal magnification factor

A distortion index *greater* than 1.00 indicates that the vertical magnification is greater than the horizontal magnification

A distortion index less than 1.00 indicates that the horizontal magnification is *greater* than the vertical magnification

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Chapter 3 - The Effect of X-ray Beam Geometry on Angular and Linear Measurements Made on a Lateral Cephalometric Radiograph of a Skull (Research Paper Two)

3.1 Introduction

Currently, radiographic images can be produced by an analog process or by a digital process. A conventional analog film image is created by the interaction of ionizing radiation and x-ray film. In the past ten years digital radiography has become more available and is used more regularly in dental offices because of many benefits it offers over traditional film based radiography. Digital radiography allows immediate image acquisition, computer archiving, computer aided cephalometric analysis, radiation dose reduction, and the environmental and cost benefit of no processing chemicals.[1,2] Digital mages can be acquired by means of digitization of radiographic films with computer scanners, charge coupled device (CCD) receptors, or a photo-stimulated storage phosphor plate (PSP).[3,4] A digital image is created when the ionizing radiation interacts with discrete picture elements (pixels) located on an x-ray sensitive plate or solid state receptor.[5] The location of each pixel is identified by row and column coordinates within the image matrix.[6]

As new technologies for cephalometric radiography have emerged, so have varying imaging projections. Traditional lateral cephalometric imaging uses a pyramid shaped x-ray beam that is applied in a static manner (Figure 3.1). For direct digital cephalometry there are two modes of image acquisition, static and scanning. The scanning CCD (charge coupled device) cephalometric machines have fan shaped x-ray beams that scan vertically or horizontally. The projection geometry produced is significantly different when compared with traditional film based cephalometric units (Figure 3.1).[7,8]

Cephalometry is an important tool in orthodontic diagnosis, treatment planning, evaluation of treatment results, and prediction of growth. The limitations of this imaging technique were identified early on and have been the topic of study in orthodontics since. In 1931, Broadbent described taking a lateral cephalogram and how to correct for magnification error created by non-parallel x-ray beams.[9] The positioning of patients in relation to the film has not changed significantly since. A patient is still positioned 5 feet from the x-ray tube and the central ray of the lateral tube passes down the length of the ear posts along their superior surfaces and meets the midsagittal plane and the film surfaces at right angles as was described by Brodie in 1949 [10] The imaging technique has become standardized over time and the inherent distortion found in cephalometric radiographs has been accepted. It is a two dimensional representation of a three dimensional object.[5] Due to the pyramidal shape of the x-ray beam the right and left sides can not be superimposed exactly. The structures on the side closest to the image receptor are magnified less than the opposite side (Figure 3.2).[6]

The problem of superimposition of bilateral structures also affects landmark identification on lateral cephalometric radiographs. Because diagnostic measurements are based on the accuracy of their placement, the limitation of landmark identification has been the topic of many studies. [4,11-16] The angular and linear measurements based on these landmarks are compared to collected norm measurements for diagnosis. Now that landmarks can be digitized, computer programs have been developed with cephalometric analyses that are automatically calculated once landmarks have been selected.[17,18] In order for these analyses to be meaningful, the magnification of the radiograph must be known for the program to calculate the measurements properly. Typically the magnification is determined using a ruler that runs vertically on the radiograph; the horizontal magnification is rarely measured separately. If the magnification factors are not the same vertically and horizontally distortion is created that is unaccounted for in the final analysis.

The aim of this study was to compare the effect of x-ray beam geometry, on radiographic images acquired of a marked human dry skull, from scanning CCD to static lateral cephalometric machines on linear and angular measurements routinely used in lateral cephalometric analyses for clinical treatment planning purposes. For this study the static units were considered the gold standard because all current norms for cephalometric measurements are based on this type of x-ray beam geometry.

3.2 Materials and Methods

3.2.1 Skull Test Design

A dry human skull was selected. Radiopaque markers consisting of stainless steel balls 1.58 mm in diameter (Small Parts, Inc. Miami Lakes, FL) were used as reference points for the chosen landmarks. These markers were fixed to the skull with cyanoacrylate following preparation with a #2 round bur. Landmark selection was based on 3 criteria: (1) the landmarks are routinely used in cephalometric analyses, (2) the landmarks have different error patterns to cover a wide range of points with different variations that are commonly used in cephalometry, (3) the landmarks were located at different distances from the central x-ray beam to calculate the distortion errors associated with their projection. The location of the landmarks was as follows (Figure 3.3):

1. sella (S): midpoint of the pituitary fossa as determined by inspection
2. nasion (N): most anterior-inferior point of the frontal bone at the nasofrontal

suture

3. A-point (A): deepest point of the curvature of the surface of the maxillary bone between ANS and the alveolar crest of the maxillary central incisor
4. anterior nasal spine (ANS): the most anterior tip of the anatomical structure of the anterior nasal spine
5. posterior nasal spine (PNS): most posterior point of the maxillary bone at the hard palate
6. gonion (Go): most convex point along the inferior border of the mandible
7. menton (Me): most inferior point of the symphysis
8. pogonion (Po): most anterior point of the midsagittal symphysis
9. B-point (B): most posterior point in the concavity along the anterior border of the symphysis

The maxillary and mandibular teeth were secured using a polyvinyl siloxane custom molded splint to ensure a stable and reproducible maxillary mandibular relationship. This was maintained with rubber bands attached to radiolucent plastic screws inserted into the dry skull.

3.2.2 Cephalometric Radiographs

The skull was positioned 15 separate times into each of the following four cephalometric units and exposed:

Unit 1: Orthoceph OC100 D (General Electric, Tuusula, Finland)
Unit 2: Orthoceph OC100 (General Electric, Tuusula, Finland)
Unit 3: Orthophos DS Ceph (Sirona Dental Systems, Bensheim,Germany)
Unit 4: Orthophos CD (Sirona Dental Systems, Bensheim,Germany)

For each unit the manufacturer's instructions on patient positioning were precisely followed. The object was to position the skull to simulate the desired position of the patient's head in the cephalometric unit. For all units involved the skull was centered to the midsagittal plane with Frankfort horizontal parallel to the floor, and the ear rods placed into the external acoustic meatus (Figure 3.4). Test exposures were made on each unit to establish kV, mA, and time setting that provided the images with sufficient density and contrast for future landmark identification.

The Orthoceph OC100 D is a horizontally scanning direct digital machine, which has a CCD receptor that is coupled with a V-shaped X-ray beam. The resulting image has a pixel matrix of 2052 X 2348. The exposure parameters were 73 kV, 15mA and 15.8 seconds.

The Orthoceph OC100 is a conventional static film based unit, which exposes the radiographic film in a static manner using a pyramid-shaped X-ray beam. The exposure parameters were 77 kV, 12mA, and 0.5 seconds. The radiographs were taken on Fuji HR –S30, 8X10 inch film (Fujifilm, Roseville, IL). Both of the General Electric units have a focal spot size of 0.35mm x 0.5mm. Each machine was certified for use.

The Orthophos DS Ceph from Sirona is a vertically scanning direct digital machine, which has a CCD receptor that is placed horizontally and coupled relative to the fan-shaped horizontally collimated x-ray beam. The resulting image has a pixel matrix of 2052 X 2348. The exposure parameters were 73 kV, 15mA and 15.8 seconds. The Orthophos CD from Sirona is a conventional static cephalometric unit, which has a pyramid-shaped x-ray beam. The exposure settings were 77 kV, 14mA, and 0.5 seconds The Orthophos CD used in this study replaced the x-ray film with a photo-stimulated storage phosphor plate (PSP) from DenOptix (Gendex, Lake Zurich, IL). The PSP was processed after every image using a DenOptix laser scanner (Gendex, Lake Zurich, IL) at a resolution of 150dpi. Both of the Sirona units have a focal spot size of 0.5mm x 0.5mm.

3.2.3 Radiographic Distance Measurements

Radiographs from Orthoceph OC100 were scanned at a resolution of 200dpi with an Epson Expression 1680 (Epson America, Long Beach, CA). Images from the four cephalometric radiograph units were saved as tiff files on a Toshiba Satellite A20 PC (Toshiba, New York, NY). For the indirect (radiographic) measurements a computer assisted method of measurement using ImageJ (NIH, Bethesda, MD) software, a public domain Java processing program was used to measure the linear measurements and angular measurements. For this study the static conventional film based units are be considered the gold standard because all current measurements are based on these types of units.

Linear Measurements were taken from (Figure 3.5):

1. SN: sella to nasion
2. NA: nasion to A point
3. NB: nasion to B point
4. NPg: nasion to pogonion
5. GoMe(LR): gonion to menton (left and right)
6. ANS-PNS: anterior nasal spine to posterior nasal spine
7. CoGo(LR): condylion to gonion (left and right)

Angular measurements were taken from:

1. SNA: sella to nasion to A point
2. SNB: sella to nasion to B point
3. PP-MP(LR): palatal plane to mandibular plane
4. CoGo-GoMe(LR): condylion to gonion to menton (left and right)
5. SNGo(LR): sella to nasion to gonion (left and right)

3.2.4 Percent Magnification

The percent magnification was determined using the formula:

$$\text{Percent Magnification} = \left(1 - \frac{\text{CCD Unit Radiographic Distance (mm)}}{\text{Static Unit Radiographic Distance (mm)}}\right) x100$$

The percent magnification was determined for all linear measurements.

The percent vertical magnification was determined using the mean percent magnification of vertical lines NA, NB, NPg, CoGoR, and CoGoL. The percent horizontal magnification was determined using the mean percent magnification of horizontal lines SN, GoMeR, and GoMeL.

3.2.5 The Error of the Method and Statistical Analysis

All skull positioning and lateral cephalometric image measurements were undertaken by the principal investigator. The total error of each image measurement was a combination of repeated skull positioning in the cephalometric unit and digitization error. For each unit the linear measurement error ranged from 0.03mm to 0.15mm (Orthoceph OC100 D), 0.03mm to 0.18mm (Orthoceph OC100), 0.03mm to 0.14mm (Orthophos DS Ceph), 0.06mm to 0.14mm (Orthophos DS Ceph) For each unit the angular measurements the error ranged from 0.01 to 0.21° (Orthoceph OC100 D), 0.01 to 0.09° (Orthoceph OC100), 0.04 to 0.19° (Orthophos DS Ceph), 0.04 to 0.61° (Orthophos CD).

3.2.6 Statistical Analysis

A repeated measure ANOVA test was performed together with post-hoc Bonferroni pairwise comparison tests to compare angular measurements between machines from the same manufacturer. The same tests were performed to compare linear measurements between machines from the same manufacturer.

3.3 Results

Mean and standard deviation values of the angular measurements are presented in Table 3.1. Repeated measures ANOVA of the angular measurements is presented in Table 3.2. Statistically significant differences were found between Orthoceph OC100 D and Orthoceph OC100 for all of the angular measurements, except PP-MPL. Between Orthophos DS Ceph and Orthophos CD there was no statistically significant difference found for the angular measurements of SNB, NSMe, or PP-MPR. All other angular measurements showed a statistically significant difference.

Mean and standard deviation values of the linear measurements are presented in Table 3.3. Repeated measures ANOVA of the angular measurements is presented in Table 3.4. Statistically significant differences were found between both manufacturers for all of the linear measurements

The calculated percent magnification for the linear measurements is presented in Table 3.5. The OC100 had an average horizontal magnification of 12.28% and a vertical magnification of 13.51%. The Orthophos CD had an average horizontal magnification of 2.19% and a vertical magnification of 3.12%.

3.4 Discussion

The dimensional accuracy of a lateral cephalometric image is determined by the horizontal and vertical magnifications. The inherent magnification seen on a lateral cephalometric image is dependant upon the position of an object between the x-ray source and the film. Ideally the amount of magnification produced from the x-ray beam geometry is equal vertically and horizontally. Scanning CCD units introduce a new x-ray beam geometry that could create differences in vertical and horizontal magnification in the final image. The conventional machines have a pyramidal shaped x-ray beam originating from a single point source, while scanning CCD units have a fan shaped x-ray beam which scans vertically or horizontally depending on the manufacturer.

The major sources of error in cephalometric analysis include radiographic film magnification, tracing, measuring, recording, and landmark identification.[19,20 21] The usefulness of results obtained with cephalometrics is limited by measurement error. The inherent distortion found in cephalometric radiographs has been accepted because the image produced is a two dimensional representation of a three dimensional object. Due to the pyramidal shape of the x-ray beam, produced from conventional machines, the right and left sides can not be superimposed exactly. The structures on the side closest to the image receptor are magnified less than the opposite side.[6]

Magnification and distortion of a lateral cephalometric image are influenced by skull morphology and head position. Skull morphology was kept constant by the utilization of a single skull. The skull was positioned in the cephalometric radiography units according to the manufacturers' directions to simulate ideal patient positioning. Therefore, the observed changes in magnification and distortion of the lateral cephalometric images are the result of differences in the imaging geometry of each radiographic unit. Also utilizing the center of the radiopaque stainless steel balls for digitization reduced the subjectivity of radiographic landmark identification.

In the Schulze[15] study, prior to identifying the landmarks, the magnification was removed from the images produced by the CCD vertically scanning, Orthophos DS Ceph, and from the conventional Orthophos CD, both from Sirona Dental Systems. The magnification was determined for one horizontal and one vertical measurement; both in the midsagittal plane, but both were partially diagonal. They reported that the effective magnification was larger for the digital images (x, 13%; y, 12%). The reported average magnification factors for the conventional unit were 1.09 along the x-axis and 1.09 along the y-axis; for the CCD unit the magnification factor was 1.25 along the x-axis and 1.22 along the y-axis. In contrast, this study revealed that the effective magnification was larger for the conventional machines. Both the horizontal and vertical linear measurements from images obtained from the OC100 were larger on average than linear measurements from images obtained from the OC100D, 12.3% and 13.5% respectively. Also, both the horizontal and vertical linear measurements from images obtained from the Orthophos CD were larger on average than linear measurements from images obtained from the Orthophos DS, 2.2% and 3.1% respectively. The differences between the Schulze study and this study could be due to the use of 3 skulls with different morphology in the Schulze study, machine calibration, measurement error, choice of landmarks, or object positioning. The most likely reason for the difference is due to the use of the PSP digitization in the current study, while the Schulze study used the analog film images directly. The software used in the PSP scanner could have changed the image size through compression in comparison the analog image.

Although statistically significant differences in angular measurements were found for all the radiographic units, many of these differences are small. It is important to determine whether these differences have any clinical significance. For example the greatest angular difference was less than 1° for both manufacturers, for the GE machines it was 0 .958° (Figure 3.6) and for the Sirona machines it was 0.543° (Figure 3.7), neither of these differences would be considered clinically significant. The smallest standard deviation for angular measurements in a common cephalometric analysis is at least 2°.

The differences found in the linear measurements between machines demonstrate the necessity of determining the magnification factor of each unit prior to completing a cephalometric analysis, especially if two films from different machines are being compared. Since the Sirona machines are more similar in magnification their linear differences are much smaller than the differences found between the GE machines. If the magnification is unaccounted for the differences in linear measurements could become clinically significant. They would especially become significant in longitudinal research measuring growth from landmark to landmark.

The results of this study can only be applied to the particular models of cephalometric radiography units utilized. In addition, the use of a single skull does not allow for the extrapolation of the results of this study to the population in general.

3.5 Conclusion

The following conclusions can be drawn from this study:

1. Statistically significant variations between linear measurements were found from lateral cephalometric images obtained from scanning and static lateral cephalometric radiography units made by the same manufacturer.
2. Statistically significant variations in angular measurements were found between lateral cephalometric images obtained from scanning and static lateral

cephalometric radiography units made by the same manufacturer.

3. There is no clinically significant difference in angular measurements between lateral cephalometric images obtained from scanning and static lateral cephalometric radiography units made by the same manufacturer.
4. There are clinically significant differences in the linear measurements between lateral cephalometric images obtained from scanning and static lateral cephalometric radiography units made by the same manufacturer.

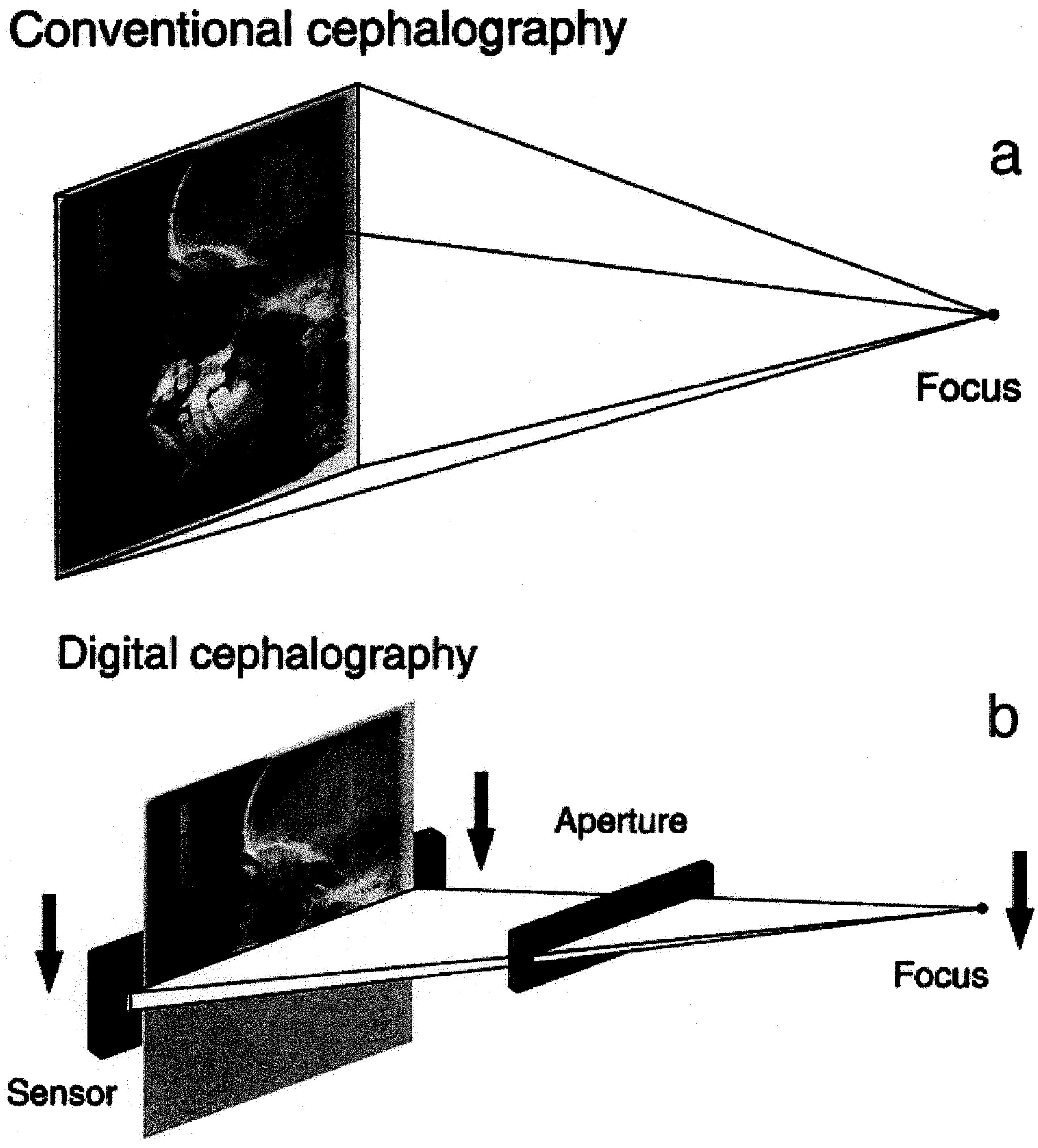


Figure 3.1 Static vs. Vertical Scanning X-ray Beam Geometry

(From Visser H, Rodig T, Hermann KP. Dose reduction by direct-digital cephalometric radiography. Angle Orthod 2001;71:159-163.)

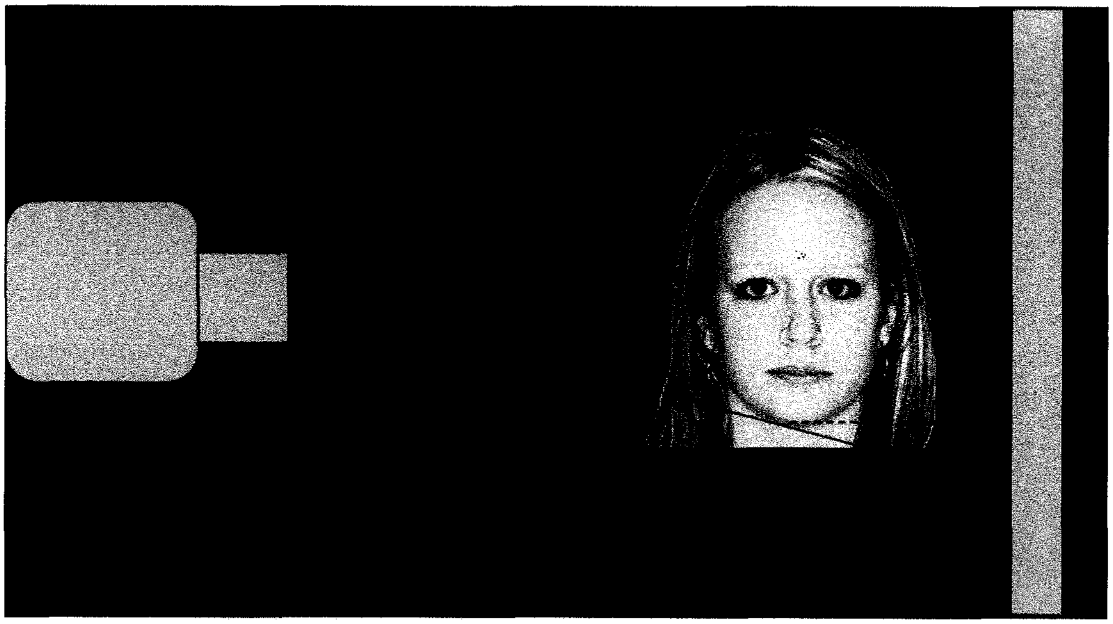


Figure 3.2 Projection of X-ray Beam

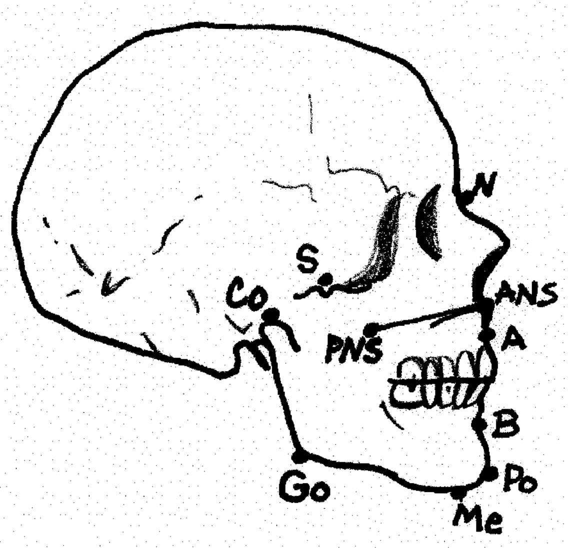


Figure 3.3 Skull Landmarks

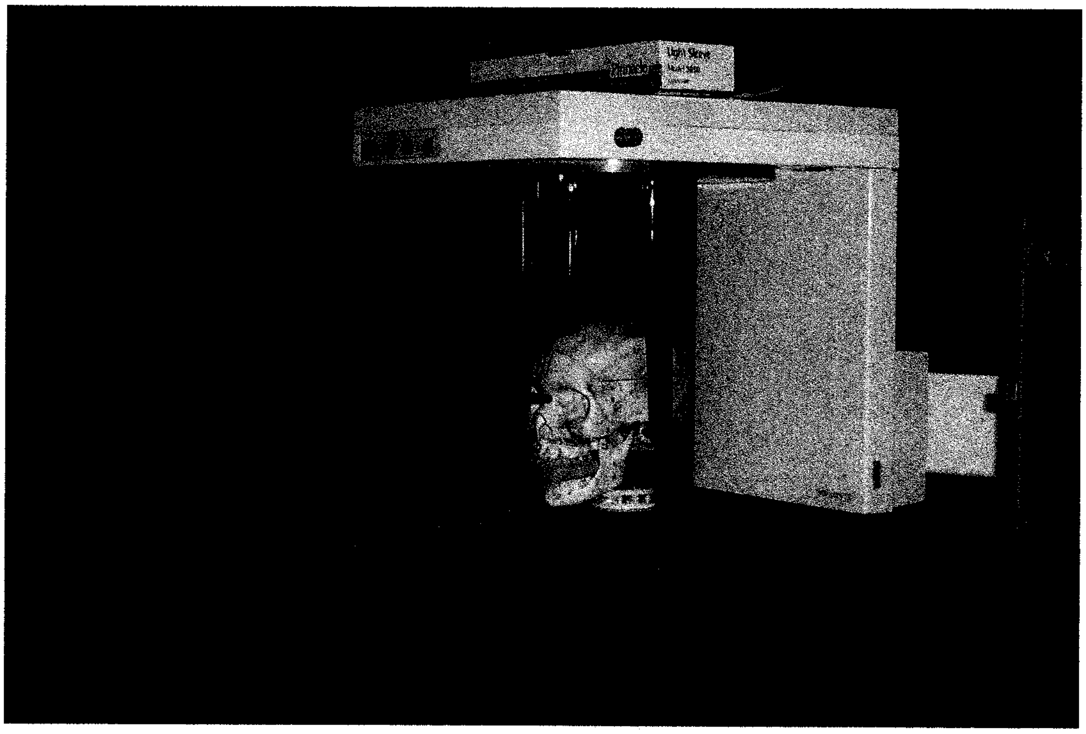


Figure 3.4 Skull Positioned for Cephalometric Imaging

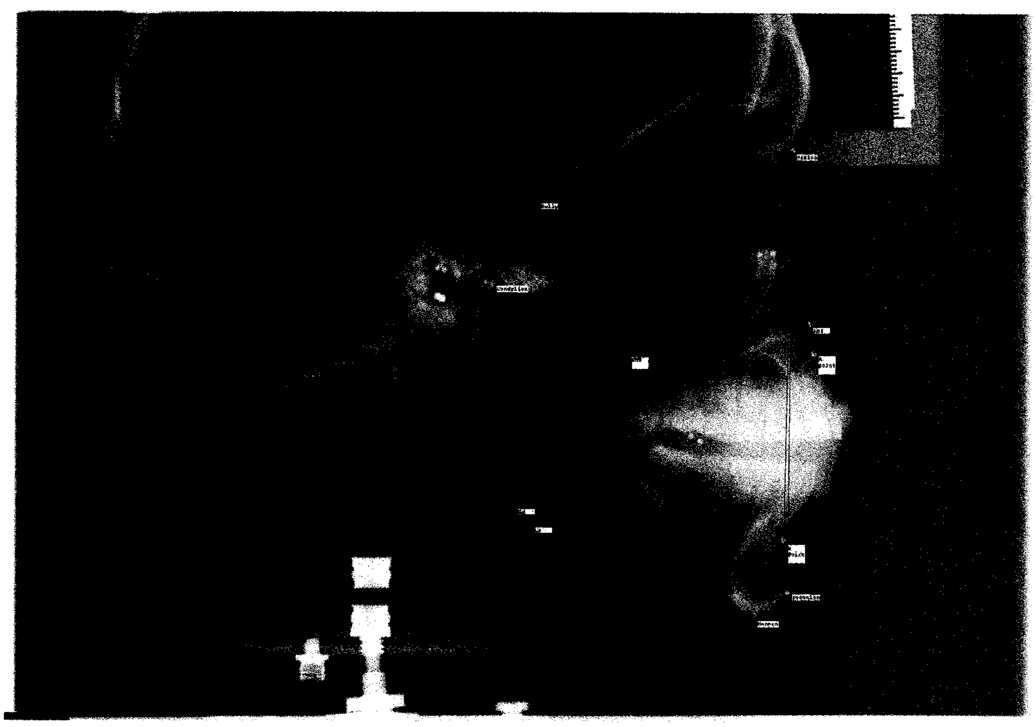
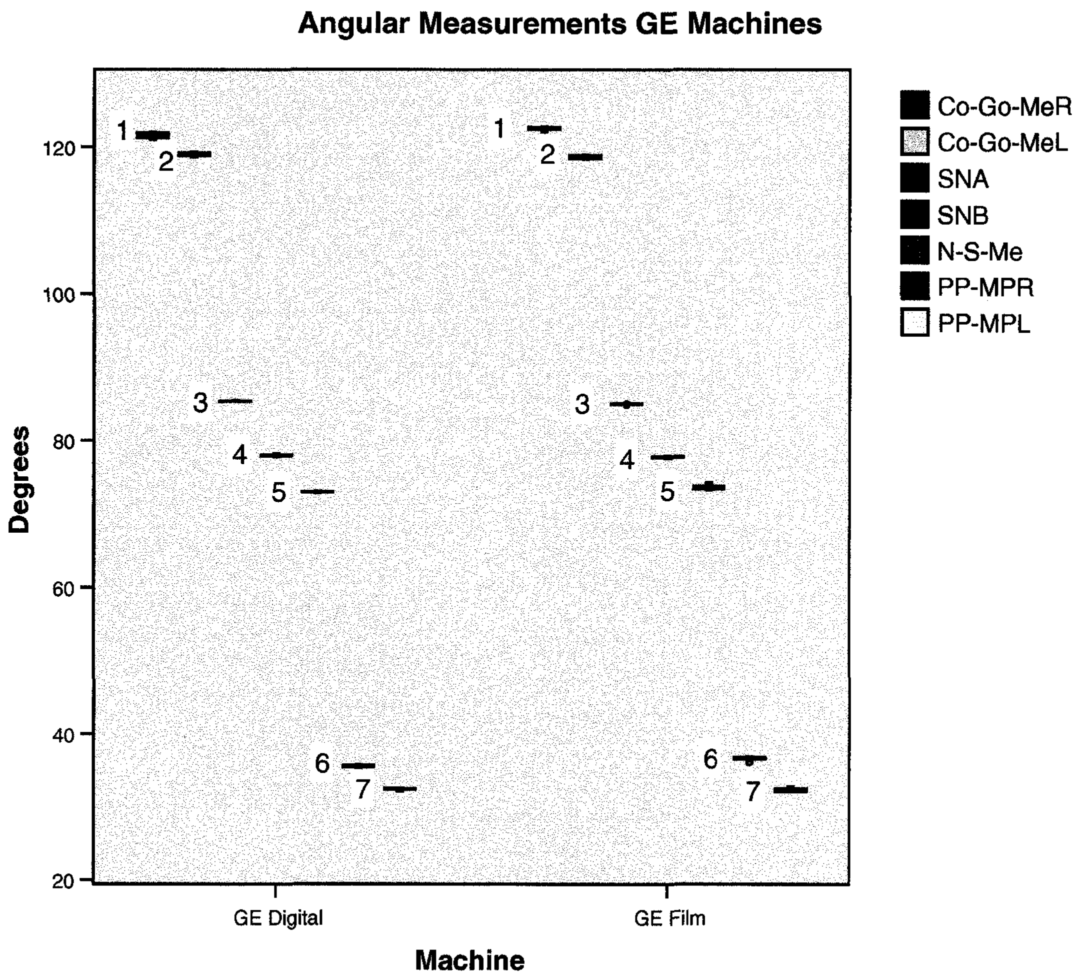


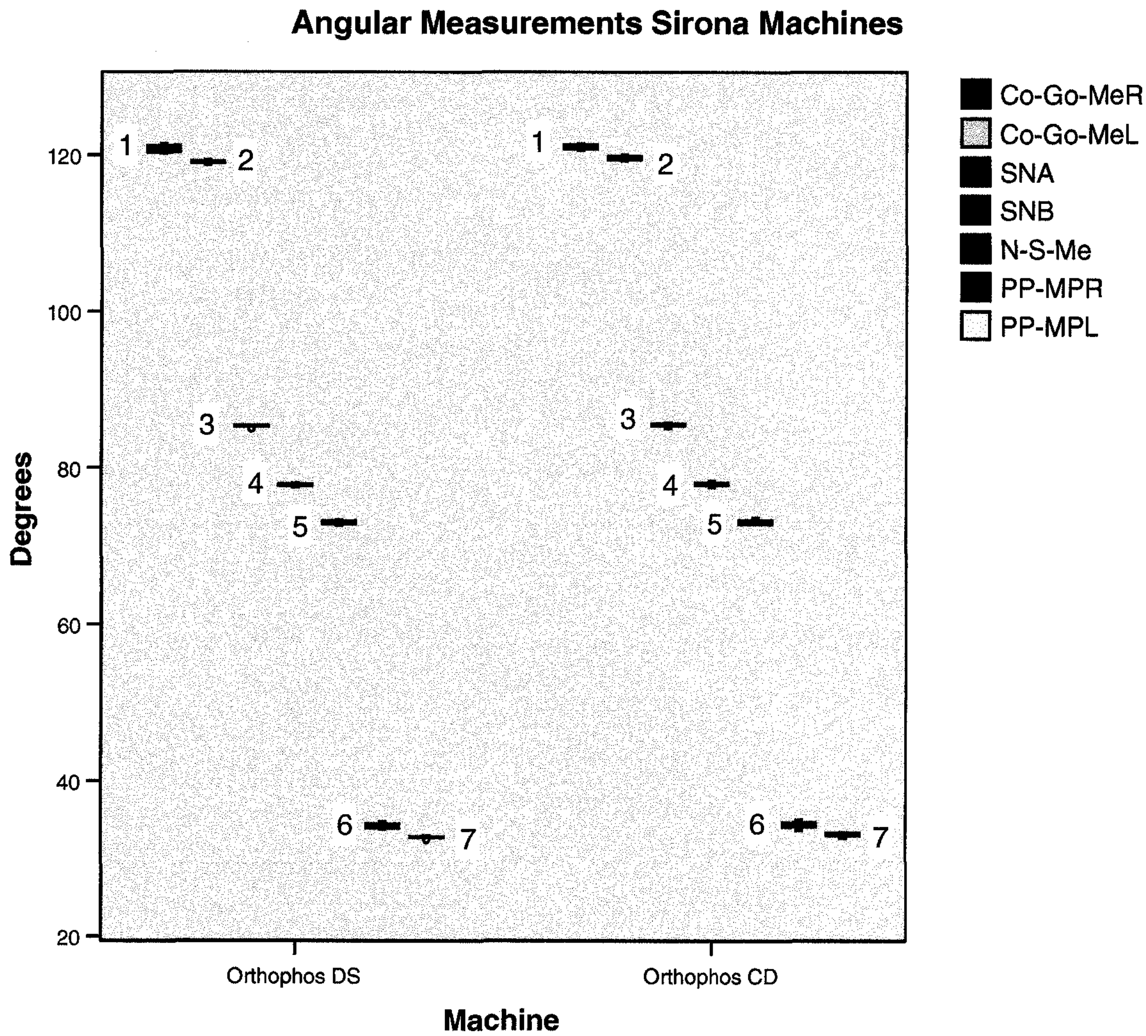
Figure 3.5 Skull Image



*box contains middle 50% of the data
vertical lines represent minimum and maximum data vaules
o represent possible outliers

1	CoGoMeR
2	CoGoMeL
3	SNA
4	SNB
5	NSMe
6	PPMPR
7	PPMPL

Figure 3.6 Boxplot of comparison of angular measurements between GE machines



*box contains middle 50% of the data
vertical lines represent minimum and maximum data vaules
o represent possible outliers

1	CoGoMeR
2	CoGoMeL
3	SNA
4	SNB
5	NSMe
6	PPMPR
7	PPMPL

Figure 3.7 Boxplot of comparison of angular measurements between Sirona machines

Table 3.1 Mean and standard deviation values for angular measurements (in degrees)

	OC100 D		OC 100		OrthophosDS		OrthophosCD	
Angle	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
SNA	85.29	0.03	84.96	0.05	85.01	0.18	85.16	0.22
SNB	78.02	0.12	77.78	0.09	77.85	0.15	77.95	0.18
NSMe	73.04	0.08	73.71	0.33	73.37	0.72	73.35	0.79
CoGoMeL	119.02	0.22	118.72	0.22	119.09	0.18	119.63	0.25
CoGoMeR	121.34	0.83	122.57	0.24	120.77	0.45	121.07	0.28
aveCoGoMe	120.29	0.29	120.64	0.01	119.93	0.27	120.35	0.15
PP-MPL	32.39	0.15	32.32	0.24	32.75	0.16	33.30	0.33
PP-MPR	35.50	0.21	36.60	0.25	34.23	0.31	34.38	0.44
avePP-MP	33.95	0.13	34.46	0.12	33.49	0.11	33.84	0.30

Table 3.2 Repeated measures ANOVA of angular measurements*

	Degree Difference			
	OC100D-OC100		OrthophosDS-OrthophosCD	
Angle	**Mean Difference**	**P-value**	**Mean Difference**	**P-value**
SNA	0.329	0.000*	-0.200	0.010*
SNB	0.239	0.000*	-0.097	0.123
NSMe	-0.665	0.000*	-0.108	0.314
CoGoMeL	0.298	0.001*	-0.543	0.000*
CoGoMeR	-0.958	0.000*	-0.304	0.035*
CoGoMe	-0.357	0.000*	-0.424	0.000*
PP-MPL	0.069	0.357	-0.417	0.000*
PP-MPR	0.083	0.000*	-0.151	0.286
PP-MP	-0.515	0.000*	-0.351	0.000*

Mean difference = angular measurement OC100D-OC100

Mean difference = angular measurement OrthophosDS-OrthophosCD

* A P-value of less than 0.050 is considered statistically significant

Table 3.3 **Mean and standard deviation values for linear measurements (in mm)**

	OC100 D		OC 100		Orthophos DS		Orthophos CD	
Line	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
SN	59.846	0.160	67.849	0.099	66.164	0.193	67.076	0.334
NA	46.511	0.171	53.740	0.189	50.529	0.323	52.177	0.314
NB	88.745	0.177	102.750	0.283	96.694	0.363	99.511	0.293
ANS-PNS	40.463	0.141	46.201	0.354	44.958	0.242	45.527	0.217
NPg	100.940	0.118	116.787	0.177	109.854	0.251	113.342	0.377
CoGoL	56.357	0.147	65.027	0.211	59.625	0.181	62.203	0.335
CoGoR	52.469	0.169	60.707	0.098	58.809	0.106	60.239	0.385
GoMeL	56.244	0.382	64.916	0.481	64.914	0.526	65.616	0.430
GoMeR	59.269	0.203	67.000	0.574	62.613	0.456	65.958	0.104
CoMeL	97.102	0.387	111.553	0.506	105.452	0.491	109.149	0.405
CoMeR	97.730	0.163	112.308	0.269	107.418	0.274	109.981	0.404

Table 3.4 Repeated measures ANOVA of linear measurements*

	Millimeter Difference			
	OC100D-OC100		OrthophosDS-OrthophosCD	
Line	Mean Difference	P-value	Mean Difference	P-value
SN	-8.00	0.00*	-0.91	0.00*
NA	-7.23	0.00*	-1.65	0.00*
NB	-15.47	0.00*	-2.82	0.00*
ANS-PNS	-5.74	0.00*	-0.57	0.00*
NPg	-15.85	0.00*	-3.49	0.00*
CoGoL	-8.67	0.00*	-2.58	0.00*
CoGoR	-8.24	0.00*	-1.43	0.00*
GoMeL	-8.67	0.00*	-0.70	0.00*
GoMeR	-7.73	0.00*	-1.90	0.00*
CoMeL	-14.45	0.00*	-3.70	0.00*
CoMeR	-14.58	0.00*	-2.56	0.00*

Mean difference = distance OC100D-OC100

Mean difference = distance OrthophosDS-OrthophosCD

* A P-value of less than 0.050 is considered statistically significant

Table 3.5 Calculated percent magnification

	Line	Percent Magnification	
		GE	Sirona
horizontal	SN	11.80	1.36
	ANS-PNS	13.36	1.07
	GoMeL	11.54	5.07
	GoMeR	12.42	1.25
	Average	12.28	2.19
vertical	NA	13.45	3.16
	NB	13.63	2.83
	NPg	13.57	3.08
	CoGoL	13.33	4.14
	CoGoR	13.57	2.37
	Average	13.51	3.12

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Chapter 4 - Discussion and Recommendations

4.1 General Discussion

Cephalometric analysis of lateral head films is an important tool in orthodontic diagnosis and treatment planning. The analysis serves as an integral instrument in diagnosis and prognosis of each case. [1] The major sources of error in cephalometric analysis include radiographic film magnification, tracing, measuring, recording, and landmark identification.[2-4] The usefulness of results obtained with cephalometrics is limited by measurement error.

Correction of measurement errors in cephalometrics used in orthodontics has been a topic of discussion since Broadbent introduced his paper in 1931 "A New X-ray Technique and Its Application in Orthodontia".[5] Because it is a two dimensional representation of a three dimensional object, the inherent distortion found in cephalometric radiographs has been accepted Due to the pyramidal shape of the x-ray beam the right and left sides can not be superimposed exactly. The structures on the side closest to the image receptor are magnified less than the opposite side.[6]

In the past ten years digital radiography has become more available and more widely used in dental offices because of many benefits it offers over traditional film based radiography. Digital radiography allows immediate image acquisition, computer archiving, computer aided cephalometric analysis, radiation dose reduction, and the environmental benefit of no processing chemicals.[7] The positioning of patients in relation to the film has not changed significantly with the addition of digital radiography, but the x-ray beam geometry has. [8]

Before conventional technologies are succeeded by new ones, the new technologies must demonstrate their diagnostic ability compared with the current gold standard, which for x-ray beam geometry in cephalometric radiographic machines, is static pyramidal x-ray beam geometry. The Orthoceph OC100 D, scanning CCD machine, operates with a vertically collimated x-ray beam that is moved horizontally through the whole exposure region and the Orthophos DS Ceph machine operates with a horizontally collimated x-ray beam that is moved vertically through the whole exposure region This is a significantly different x-ray beam geometry than their manufacturer's conventional counterparts, respectively the Orthoceph OC100 and Orthophos CD, which have a pyramidal shaped beam applied in a static manner.

The purpose of the first study was to use a radiographic phantom of known dimensions to evaluate the measurement of magnification and distortion on lateral cephalometric images, at specific distances from the x-ray source, produced by scanning CCD and static cephalometric radiograph units. The images produced were two dimensional images of a two dimensional sheet, eliminating the distortion produced by creating a two dimensional image of a three dimensional object. The purpose of the second study was to compare the effect of x-ray beam geometry, on radiographic images acquired of a marked human dry skull, from scanning CCD to static lateral cephalometric machines on linear and angular measurements routinely used in lateral cephalometric analyses for clinical treatment planning purposes. For both of these studies the static units were considered the gold standard because all current norms for cephalometric measurements used in orthodontics are based on this type of x-ray beam geometry.

The results of the first study demonstrated statistically significant differences in magnification factors, angular measurements, and distortion indices for all the radiographic units. The distortion indices for the machines were the most interesting finding because distortion is a function of magnification and if it is present it affects the angular measurements. Two of the machines demonstrated a distortion index of 1, the horizontal scanning GE CCD unit, Orthoceph OC100 D, and the static Sirona unit, Orthophos CD. Therefore, they both had equal horizontal and vertical magnifications. The static GE unit, Orthoceph OC100, had a distortion index indicating that the vertical magnification factor was greater than the horizontal magnification factor. This index was constant at all distances from the image source. The vertical scanning Sirona CCD unit, Orthophos DS had a distortion index that was different at every distance from the image source. The central position, most like that of mid sagittal plane, had minimal differences in vertical and horizontal magnification (distortion index = 0.99). In general, the horizontal magnification factor increased as the object was moved closer to the image source, which is expected, but the vertical magnification factor remained constant at every distance. This is unique to this machine. The radiographic images produced by the Orthophos DS are affected by the change in the x-ray beam geometry created by the vertical scanning.

The results of the second study demonstrated statistically significant differences in angular and linear measurements for all the radiographic units. The differences in the angular measurements between machines would not have been great enough to change a treatment plan or a clinical outcome and therefore, would not be considered clinically significant. The differences in linear measurements were a function of magnification. The Sirona machines were more closely matched in magnification and therefore demonstrated less difference in linear measurements, although statistically significant.

This demonstrates the need to correct for magnification, especially if trying to compare radiographs obtained from different machines. The magnification becomes even more significant when trying to compare two radiographs over time from different machines, as would be done in growth studies. Most of the cephalometric measurements used in treatment planning are angular or are a ratio of two linear measurements from the same machine; in both of these cases the magnification is irrelevant as long as it is equal vertically and horizontally. The shorter the linear measurement the less its magnification affects the clinical significance, because typically the range of normal is at least 2mm.

When evaluating the results of the two studies together the difference between statistical significance and clinical significance is apparent. The phantom study was able to clearly demonstrate where the differences between measurements in machines arose. If one was to only use that study to determine which machine would produce the least accurate lateral cephalometric images the Sirona Orthoceph DS would most likely be chosen because it had the greatest difference in distortion as the object was moved towards and away from the image source. But when all those layers are combined, as in a skull, that machine has an average distortion index of 0.99, which clinically would not be significant. Also the phantom had the advantage of all objects being imaged lying in the same plane. Only the structures in the midsagittal plane of a skull come close to this. Not only are mandibular measurements bilateral, so one side is much closer to the image receptor than the other, the measurements made from them are often tapering towards the midsagittal plane creating foreshortening of that structure. Since the difference in the angular measurements of the skull between all the machines was not clinically significant the difference in the distortion between the machines would not be clinically significant either.

4.2 Limitations of the Current Study

After analyzing the data obtained from this study, some limitations became apparent. The primary limitation of this study was the use only one machine of each type of lateral cephalometric unit. The differences found between machines can not be extrapolated to all machines of this type made by that manufacturer. They could be calibration errors specific to that individual machine. Another limitation of this study was that teeth were not used in the skull study. Many of the smaller linear measurements used clinically in lateral cephalometric analyses are from the dentition. It would have been valuable to see the affect of magnification and distortion on smaller linear and angular measurements. Since the objective of this study was to compare images between machines the true lengths of the skull were not used to find true magnification and distortion on the images produced of the skull. It would have been interesting the see the true affect each machine had on magnification and distortion of specific anatomical structures.

4.3 Recommendations for Future Studies

Future studies could include multiple machines made by the same manufacturer to evaluate if the results from this study are consistent throughout machines of the same brand. Another study could evaluate error correction on lateral cephalometric images by using the vertical and horizontal magnification factors found from images taken at the middle slot of the phantom.

In addition, lateral cephalometric-like images obtained from cone beam volumetric scanning units (CBCT) such as the NewTom® or other three-dimensional imaging systems such as the i-CAT® using the marked human dry skull would be of interest. The inherent distortion and measurement errors of a lateral cephalometric image can only be removed when a three dimensional image is produced and measured. This would allow comparison of true angular measurements to cephalometric norms so that new norms can be created without the error incorporated from the distortion produced by the current lateral cephalometric images. This could become a useful tool for future clinicians when assessing facial and dental patterns.

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