INTRODUCTION

Radiographs are an important part of dental diagnosis and treatment planning. Radiographs are often used in many branches of dentistry to assess vertical linear measurements. For example, in the assessment of root canal length, measuring the extent of lesions or fractures prior to surgery, in measuring certain points in orthodontics and evaluation of bone architecture in the pre- and post implant phases ***(Wakoh et al., 2006).***

Several imaging techniques have been investigated, ranging from conventional intraoral radiographs to the most advanced digital imaging methods. Images generated either conventionally or digitally must allow acquiring measurements that can reproduce the real conditions ***(Langlois et al., 2011).***

Periapical radiography is easily available, simple to handle, with high resolution and low cost. It provides a satisfactory relationship between the film and the long axis of the alveolar bone ***(Langlois et al., 2011),*** with proper positioning techniques, periapical radiographs give minimum magnification and distortion and the reproducibility of these radiographs is high ***(Siu et al., 2010)***, being an important resource for analysis of anatomical structures ***(Langlois et al., 2011),*** thus is well suited for documentation and assessment of possible peri-implant bone resorption during follow-up and is considered superior to panoramic radiography in this respect.

Nevertheless, the size of the film is often inadequate for the depiction of all the anatomic borders of interest for pre-implant examinations. An edentulous alveolar ridge may not have the same long axis as a tooth; the image of the alveolar bone in the region of interest may be distorted, either foreshortened or elongated. It provides only a lateral view of the selected potential implant site without cross-sectional information, and the projections are not always perfect due to problems with film placement in resorbed jaws. This can cause inaccurate measurements in intraoral radiographs ***(Siu et al., 2010).***

Many dentists only use panoramic radiography for dental implant assessment, despite the improved measurement accuracy given by three-dimensional imaging methods such as cone beam CT ***(Devlin et al., 2013).***

The major disadvantages of panoramic radiography are an unpredictable distortion of the visualized structures and a low level of reproducibility. Accurate assessment of hard tissue morphology and density is impossible because of the variable distortions occurring in different parts of the radiograph ***(Siu et al., 2010).***

Even when properly taken, dental panoramic images are associated with enlargement of the actual object size by about 15–25%, and distortion occurs when horizontal magnification differs from vertical magnification with poor patient positioning ***(Devlin and Yuan, 2013).*** Measurement of mandibular anatomy is problematic when using panoramic radiography. Previous studies suggest that projection geometry, focal plane shape, differential vertical and horizontal magnification factors, and operator error in patient positioning affect the utility of panoramic images to provide accurate measurements ***(Ludlow et al., 2007).***

A number of mandibular indices based on panoramic radiographs, and image processing and analyzing techniques have been developed to allow quantification of mandibular bone mass and trabecular architecture in order to discriminate individuals with osteoporosis from those without osteoporosis. Cortical width (CW), panoramic mandibular index (PMI), alveolar crest resorption degree (M/M) ratio, cortical index (CI) and fractal dimension (FD) are among them. In various studies, it has been shown that the decreased bone mineral density (BMD) affects the morphometric, densitometric and architectural properties of mandibular bone in the osteoporotic patients on radiographs ***(Melescanu-Imre et al., 2009).***

Since the introduction of cone beam CT (CBCT) to the field of dento-maxillofacial imaging in the late 1990s, its usefulness to various disciplines of dentistry has been well described. Because of its relatively low radiation and cost, the technique has gained widespread use in various dental fields, such as oral implant surgery, orthodontics and endodontics. In these specialties, use of linear measurements is a necessity for accurate treatment planning ***(Lund et al., 2009).***

Complex computer algorithms are required to convert 3D medical and cone beam CT volumes to images that simulate 2D panoramic radiographs, by removing all voxels information that lie outside the specified focal trough. Panoramic reconstruction from the CT data improves image clarity by reducing geometric distortions, blurring and artifacts from superimpositions ***(Tohnak et al., 2006).***

When CBCT data are available, CBCT-generated panoramic views can be considered as an alternative to conventional panoramic imaging ***(Mischkowski et al. 2007).*** Comparing these two modalities, ***Mischkowski et al. (2007)*** found that subjective image quality was ranked higher in panoramic radiographs than in CBCT panoramic views due to noise, poor contrast, and artifacts caused mainly by metallic dental restorations in the CBCT images. No significant difference between the two types of images was found regarding the detection of pathology, though. Furthermore, CBCT panoramic views were superior to panoramic radiographs for identification of the mandibular canal ***(Angelopoulos et al., 2008).***

The purpose of this study was to evaluate the efficacy of the most frequently used digital radiographic techniques in dental measurements; digital Intra-oral periapical radiographic imaging using PSP system, directly generated CBCT images, and digital panoramic radiographic images derived from conventional and CBCT generated methods, regarding their linear measurements' accuracy in different anatomical sites in dry human mandibles compared to the gold standard direct measurements obtained by a digital vernier caliper.

Review of Literature

Digital Radiographic Imaging

Conventional radiographic film consists of silver halide grains in a gelatin matrix. When a film is exposed to x-ray photons, silver halide crystals are sensitized and then reduced to black during the developing process. The film acts both as the radiation detector and imaging display ***(Brennan, 2002).***

One of the goals of recent advances in imaging modalities has been the replacement of the "film – based technology" with computer – based devices that use electronic X- ray photon detectors to record the radiographic image ***(David et al., 1992).*** With the advent of digital computers and the subsequent development of powerful microcomputers, the possibility of replacing films as a photon detector took a big leap forward ***(Borg and Grandahl, 1996).***

In digital radiography, instead of the silver halide grains, a digital image is composed of a large number of very small pieces of information known as ‘pixels’ (picture elements). Pixels forming an image are not randomly distributed throughout the image; instead, they lie in specific cells formed by a layout of rows and columns, known as ‘digital image matrix’. The image matrix size corresponds to the number of rows by the number of columns. The pixel size directly affects the digital image details, and the smaller the pixel size, the more detailed the digital image will be ***(Angelopoulos et al., 2004).***

However, unlike film, the sensors are the only radiation detector and the image is displayed on a monitor ***(Brennan, 2002).*** Moreover, the pixels' size is related to image resolution. Resolution is the ability of an imaging system to distinguish between small objects that lie very close to one another. The image acquisition process is the main factor determining the resolution of an image. Each pixel in the digital image is represented by a number that corresponds to brightness with which a pixel can be displayed on a screen (computer monitor). This number is known as 'pixel value' or 'pixel intensity' and is proportional to the brightness of the specific pixel; the higher the pixel intensity, the brighter the pixel, and vice versa ***(Versteeg et al., 1997 and Angelopoulos et al., 2004).***

The main determinants of the radiographic image quality include image resolution and image noise. In film-based panoramic radiography, these factors are affected by the physical properties of the radiographic film and intensifying screens, whereas in digital imaging, they are affected by the physical characteristics and limitations of the detectors and the hardware involved in the image acquisition process ***(Angelopoulos et al., 2004).***

The number of grey levels relates to contrast resolution and the size of the pixels is related to spatial resolution. Together these determine the overall resolution of an image. Resolution can also be expressed in line pairs per millimeter. Most conventional E speed films have a resolution of 20 LP/mm whereas with digital images the resolution ranges from 7-10 LP/mm. The reduced resolution should not interfere with clinical diagnosis ***(Brennan, 2002).***

The pixel value corresponds to a specific gray shade, since all the images encountered are “black and white.” The range of brightness levels (or shades of gray in digital radiography) that can be displayed on a screen, is affected by the digital bit depth, which is the number of bits (binary digits) that quantize each pixel. A bit is a very small piece of data that can take only two values in the binary system, either 0 or 1, (most computers operate with the binary system) ***(Angelopoulos et al., 2004).***

Any digital imaging system should include some essential properties as follows: (1) the image produced should be of diagnostic quality; (2) the radiation dose is less or even equal to that required for a conventional film; (3) digital radiographic techniques should be compatible with conventional x-ray generators; (4) The lossless archiving should be allowed in the imaging file format promoting interoperability (DICOM standard); and (5) the time required for the total procedure should be equal to or less than that with the film. The detector needs not to be identical to a film in all image properties; however, it should provide sufficient information for necessary diagnosis. The information needed might be task dependent: e.g., high spatial resolution is needed to accurately measure the lengths of fine endodontic instruments, but would not be necessarily required in the detection of proximal surface dental caries. It should be remembered that the ideal detector should be able to multitask; also, both sufficient spatial resolution and good contrast discrimination are needed ***(Farmanand Farman, 2005).***

❖ *Digital Radiography Image Receptors:*

Include direct and semi direct digital imaging. Direct digital images are acquired by using a solid state sensor. The solid state sensors are based on a charge coupled device (CCD) or complementary metal oxide semi conductor (CMOS) based chips. The semi direct images are acquired using a phosphor plate system, which is called computed digital radiography ***(Van der stelt, 2005).***

An alternative option to a fully digital system is scanning that convert conventional film radiographs into digital images ***(Digitization)***. This allows image quality to be enhanced (when necessary) and the images can be quantitatively analyzed using on-screen software. However, it has been suggested that valuable diagnostic information can be lost during the digitization procedure, with artifacts and noise being introduced. In addition, the radiation dose for the patient and the working time are not reduced as the radiographic technique is not altered ***(El-Angbawi et al., 2012).***

- ***<u>Indirect Acquisition (Digitization):</u>***

A digital image can be produced by scanning conventional radiographs using a flat bed scanner and a transparency adaptor, or by using a charged coupled device camera instead of the flat bed scanner. This image can then be manipulated using software packages or be passed on to a second party via a modem ***(Brennan, 2002).***

A process by which analog information (continuous values) are converted in to digital ones (discrete values). This process is a necessary function for computer imaging applications, as visual information is inherently in analog format, and most computers can use information only in a digital form. Digitization consists of two steps: sampling in space, which affects the spatial resolution, and quantization in signal intensity, which affects the grayscale bit depth and may give rise to quantization noise ***(Krupinski et al., 2007).***

- ***Direct digital imaging:***

There are two systems available, one produces the image immediately on the monitor post-exposure and therefore called direct imaging. The second has an intermediate phase, whereby the image is produced on the monitor following scanning by laser. This is known as Semi-direct imaging ***(Brennan, 2002).***

i. Direct digital imaging; solid state detectors:

Solid-state detectors vary in construction; presently, however, they all consist of a charge-coupled device (CCD) or complementary metal oxide semiconductor (CMOS) chip, that are sensitive to light and a scintillator layer that converts x-rays to light. There may be an intervening fiber-optic or the scintillator can be applied directly to the chip. The quality of an image produced by a solid-state detector not only depends upon the chip pixel dimensions, but also upon the type and configuration of the scintillator layer, the electronics including analog to digital conversion, and the acquisition and display software ***(Farman and Farman, 2005).***

➢ ***Charge-coupled device (CCD):***

An electronic detector, that is sensitive to light or x-rays and can generate electric charges in proportion to the amount of light or x-rays striking it. A scintillator, which is coupled to the detector fiber-optically, produces light energy when being hit by x-rays. Thus, x-ray energy is converted to light energy just before reaching the detector ***(Farman et al., 1998 and Van Der Stelt, 2000 and Angelopoulos et al., 2008).***

This process actually reduces the patient exposure, as the scintillator intensifies the x-ray energy when converting it to light. An analog-to-digital converter (ADC) will convert these electric charges to a digital format by assigning a number to each of them in proportion to the electrical energy, where this number represents the pixel intensity value in shades of gray of the specific location of the digital image ***(Farman et al., 1998 and Van Der Stelt, 2000 and Angelopoulos et al., 2008).***

The sensor cannot store information and must be connected via fiber optic wires to the monitor, which can make the sensor bulky and awkward to use ***(Brennan, 2002).***

Figure (1): Direct digital receptors are of rigid construction with an attached electrical cable *(Schick Technologies, Inc., Long Island City, New York)* ***(Williamson, 2014)***.

- ***<u>Complementary metal oxide semiconductor (CMOS):</u>***

A photosensitive device consisting of an array of individual picture elements (pixels) etched on a crystalline silicon wafer and manufactured using the standard random access memory production process. Light falling on the array produces a proportional charge that is stored in each element. Interconnections between pixels allow for direct addressing, digitization of the accumulated charge, and refreshing the array for the next image capture event ***(Krupinski et al., 2007).***

ii. <u>Semi-direct digital imaging; Photostimulable phosphor plates (PSP):</u>

These are plates covered in phosphor crystals layer. Also referred to as; storage phosphor plates. This phosphor layer can store the energy of x-ray photons for some time. A scanner is required to “read” the image information, by scanning the plate with a laser beam of near red wave length. The energy is then released from the phosphor layer, detected by an image intensifier and subsequently converted in to a digital image ***(Van der stelt, 2005).***

The laser beam is focused to a spot of 70 um in diameter, and directed on to the plate surface. The pixel size in phosphor plate systems depends on the focal spot of the laser beam and the accuracy of movement of the plate or the laser beam in the scanner ***(Araki et al., 2000).***

In those scanners, the x-ray energy will be released, and then converted in to electric charges. Each electrical signal is assigned to a number proportional to its intensity through an analog-to-digital converter (ADC). This number represents the pixel intensity value in shades of gray, which is based on the x-ray energy that was initially stored on the area of the plate. After completion of the scanning process, the PSP is flooded with bright light to erase any remainder of the latent image and rendering the plate ready for further exposures ***(Hildebolt et al., 2000 and Parks and Williamson, 2002).***

The latent image remains on the phosphor plate before the scanning phase for minutes to hours, depending on the environment where the plates are stored. They should not be exposed to bright light or warmth, as this releases the stored energy before being used by the scanner. After scanning of the plates, they are exposed to bright light that erases all the remaining energy; then the plates can be reused ***(Van Der Stelt, 2005).***

Photostimulable plates possess some advantages over conventional radiographic films, such as the efficient formation of the latent images, as these plates absorb more energy than the conventional films, and thus require shorter exposure time. Finally, the image is obtained electronically, eliminating chemical processing, and the plates are also re-usable ***(Freitas et al., 2006).***

However; the signal resulting from a digital photostimulable phosphor imaging system might be affected by a low incidence of photons (short exposure) and thus generate a smaller number of luminescence centers, which in turn causes a low signal. Consequently, there is an increase in photon noise, which can cause a non-uniform density distribution. Another factor that might cause reduction in the signal of this system, is fainting of the latent image over time due to phosphorescence.

These two types of signal loss can compromise the pixel values attributed to a radiographic image ***(Freitas et al., 2006).***

a **b**

Figure (2): a. Different sizes of Photostimulable phosphor plates

b. Exposed PSP receptors must be scanned to release the stored energy, digitize the image and display it on a computer monitor. A scanning device is pictured in the left foreground ***(Air Techniques, Inc., Hicksville, New York) (Williamson, 2014).***

❖ ***PSP Imaging Artifacts:***

These artifacts include; Acquisition artifacts, post acquisition artifacts and display artifacts.

***1. Acquisition artifacts*:**

Acquisition artifacts are: (1) phantom image, due to incomplete plate erasing as over-exposure may require two erasing cycles; (2) scratches, which are permanent defects that may require imaging plate replacement; (3) light spots, caused by dust or foreign material on the plate; (4) drop out artifacts, resulting from reduction in the overall resolution or only in some areas due to dust accumulation; (5) Fogging, plates are more sensitive than films; (6) quantum mottle or reticulation (image noise), caused by under exposure, as decreasing the number of photons reaching the image receptor increases the amount of quantum mottle and vice versa, also called salty and pepper appearance indicating inhomogeneous appearance; and (7) heat blur, caused by exposure of the image receptor to intense heat ***(Carlton and Adler, 2006).***

2. Post acquisition artifacts:

They include; (1) drop out artifacts, due to laser imaging equipment problems; (2) laser film transport artifact, due to uneven scanning; (3) distortion or overlapping, histogram error, caused by incorrect pre-processing histogram selection; and (4) algorithm artifacts, related to processing functions that are available on specific computed radiography systems ***(Carlton and Adler, 2006).***

3. Display artifacts:

Include; (1) density/brightness window level adjustment artifacts; (2) contrast window width adjustment artifacts; (3) electronic magnification and minification and image enhancement artifacts ***(Carlton and Adler, 2006).***

The processing of a photostimulable phosphor plate requires laser scanning, photomultiplication and analog to digital conversion of the resulting signals. This process requires seconds to minutes. The time is greater when high spatial resolution is desired as this requires a smaller scanning pitch to be applied. The quality of an image from a photostimulable phosphor depends not only on the quality of the phosphor plate itself, but also on the scanning mechanism, electronics, acquisition and the display software ***(Farman and Farman, 2005).***

Gray-scale: The number of different shades of gray that can be stored and displayed by a computer system is related to the number of bits used in digitization. Each bit is binary, composed of a 0 or 1, so the total number of gray levels is the bit depth raised to the power of two: 8 bits = 2^8 = 256 gray levels, 10 bits = 1,024 gray levels, and 12 bits = 4,096 gray levels ***(Krupinski et al., 2007).***

Dynamic range: The difference in signal intensity, or frequency, between the largest and smallest signals a system can process or display. The optical density is the difference between the lightest and darkest useful regions of the image. Increasing the number of bits per pixel in a digital image increases the dynamic range of an image ***(Krupinski et al., 2007).***

In conventional screen-film combination, the dynamic range gradation curve is S-shaped within a narrow exposure range for optimal film blackening; thus, the film possesses low tolerance effect for an exposure that is higher or lower than required, resulting in exposure failure or insufficient image quality. For digital detectors, dynamic range is the range of x-ray exposure over which an image can be obtained. Digital detectors have a linear and wider dynamic range, which in clinical practice eliminates the risk of exposure failure. Another positive effect of a wide dynamic range is that the differences in specific tissue absorption (e.g., bone and soft tissue) can be displayed in one image without the need