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ORIGINAL ARTICLE

The validity of different display monitors in the assessment of dental implant site dimensions in cone beam computed tomography images

ASMA'A A. AL-EKRISH, MOHAMED I. H. EKRAM, WAFA AL FALEH, MUSTAFA ALKHADER & RA'ED AL-SADHAN

Department of Oral Medicine and Diagnostic Sciences, College of Dentistry, King Saud University, Riyadh, Saudi Arabia

Abstract

Objective. To determine if the differing contrast resolution of various LCD monitors affects the reliability or accuracy of measurements of proposed implant sites. ***Materials and methods.*** Edentulous areas of human dry skulls were marked with radiopaque markers in order to standardize the plane of the transverse cross-sections of the ridges and path of measurements. The skulls were imaged by a CBCT device and the images stored in proprietary format on the workstation. The data sets were then transferred, with the proprietary reformatting software, to two different laptops using CDs. Transverse cross-sectional images of the ridges were reformatted on all three computers and ridge dimensions were recorded using the linear measurement tool of the proprietary software. Ridge dimensions were recorded directly from the three different monitors by two observers and compared to measurements recorded directly from the bone. The measurement errors and intra- and inter-examiner reliability were calculated for each monitor and compared with each other. ***Results.*** Intra- and inter-examiner reliability scores for the measurements recorded from all three devices were very high and ranged between 0.993–0.999. The mean of the absolute errors was 0.55 mm for the workstation, 0.61 mm for laptop 1 and 0.68 mm for laptop 2. The absolute errors were statistically significant for all three monitors (p-value < 0.001), but there was no statistically significant difference between the absolute errors obtained from the three monitors. ***Conclusions.*** No differences in the reliability or accuracy of measurements of implant site dimensions were obtained using color LCD monitors with different contrast resolution capabilities.

Key Words: *CBCT, computer terminals, radiography, dental, digital, reliability*

Introduction

Implant therapy is rapidly becoming available to an increasing numbers of patients. Implantologists have a variety of diagnostic tools at their disposal during implant site assessment. However, three-dimensional imaging of the jawbones using cone beam computed tomography (CBCT) is one of the most accurate and reliable methods for measuring implant site ridge dimensions [1–7]. When CBCT images are acquired, measurements of implant sites may be recorded directly from the workstation connected to the CBCT device or they may be transferred to personal computers for analysis either by the radiologist or the implantologist. Analysis of the CBCT data on other computers equipped with dedicated implant planning software may offer improved implant site analysis compared to the proprietary software programs of some CBCT devices. However, computer monitor specifications may differ between the CBCT workstations and personal computers, with varying contrast and spatial resolution between display monitors. Since accuracy of implant site measurements recorded directly from a monitor depends on the ability of the operator to identify anatomic landmarks clearly, the question arises as to whether the difference of contrast resolution parameters may lead to clinically significant differences in the accuracy of measurements recorded from different monitors.

Workstations for CBCT devices generally incorporate liquid crystal display (LCD) monitors (flat panel displays). The quality of digital images viewed on an LCD display may be affected by the spatial resolution and contrast resolution capabilities of the monitor [8–10]. Many factors can affect the contrast and spatial resolution of these display monitors. Such

Correspondence: Asma'a A. Al-Ekrish, PO Box 56810, Riyadh, 11564, Kingdom of Saudi Arabia. Tel: +00 966 1 4677423. E-mail: asma.alekrish@gmail.com

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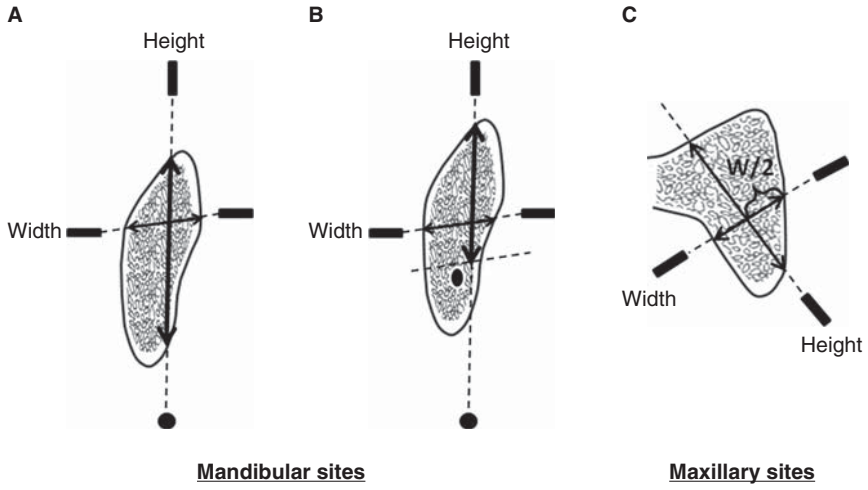

Figure 1. Diagram showing the relationship of the radiopaque markers to the edentulous ridges and direction of the height and width measurements on transverse cross-sections. (A) Mandibular section, anterior to the mental foramen. (B) Mandibular section, at and posterior to the mental foramen. (C) Maxillary section.

factors may include viewing distance and angle, maximum and minimum luminance, the luminance response (characteristic) curve, grayscale bit depth, background ambient lighting and display software [8–11]. Studies in the medical literature have found that such factors can affect the diagnostic outcome for a variety of diagnostic tasks [12,13].

In dentistry, some studies have found that various LCD monitor settings and viewing conditions may indeed affect caries diagnosis [14–16], while others have obtained mixed results [17]. Ilgüy et al. [14] compared a color LCD computer monitor with a 3-megapixel monochrome display medical monitor in the detection of artificial caries and found a higher diagnostic accuracy with the use of the medical monitor. Hellen-Halme et al. [16] investigated how the brightness and contrast settings of the display monitor and ambient light level in the viewing room affect the clinician's ability to diagnose carious lesions. They found that reducing ambient light significantly increased the accuracy of diagnosing proximal carious lesions on a flat panel monitor with an optimal brightness setting and an optimal or slightly higher than optimal contrast setting. On the other hand, the study by Isidor et al. [17] compared the accuracy of five flat panel monitors for detection of proximal caries and found one monitor achieving significantly higher sensitivity than two of the other monitors, with no difference between the remaining monitors. The same monitor was found to have significantly lower specificity than the other two monitors, with no significant differences observed between the remaining monitors. They concluded that no clear relationship between diagnostic accuracy and price of the monitor was found [17].

However, from a review of the literature at the time of writing, and to our knowledge, there are no published studies comparing the objective performance of different LCD monitors during implant site assessment. Thus, the aim of our study is to determine if there is a difference in reliability and accuracy of measurements of ridge dimensions of proposed implant sites using LCD monitors with different contrast resolution capabilities.

Materials and methods

Preparation of skulls

Five human dry skulls were used in this study. All existing teeth were removed and the alveolar ridges were flattened to expose areas of bone which would facilitate physically sectioning the bone while maintaining the height and width of the ridge at the site of the sections. After grinding, the surface of one of the maxillae was found to be entirely made up of exposed large marrow spaces and was, therefore, not used for measurement purposes. The corresponding mandible was used, though, and the entire skull was imaged in order to facilitate proper positioning of the mandible.

The edentulous areas to be measured were marked with radiopaque gutta percha markers, 1.4 mm in diameter. The markers delineating each sample site were placed crestal, buccal and lingual to the jaws and a groove filled with softened gutta percha was also placed along the inferior border of the acrylic resin surrounding the mandible. The markers and gutta percha groove were thus placed in order to delineate the position and plane of the transverse cross-sections as well as the proposed path of measurements, as outlined in Figure 1.

The markers were obtained by cutting the black color-coded ends of size 80 gutta percha cones with scissors and were embedded in a layer of clear acrylic resin separated from the bone by three layers of sheet wax (each layer 1.5 mm thick). The wax and the acrylic

Table I. Distribution of sample sites.

	Maxillary sites			Mandibular sites			
Skull	Incisor	Canine-premolar	Molar	Incisor	Canine-premolar	Molar	Total
1	0	2	2	1	0	0	5
2	1	0	1	1	1	1	5
3	0	0	0	0	1	1	2
4	2	1	0	1	1	1	6
5	1	1	1	1	1	1	6
Total	4	4	4	4	4	4	24

resin surrounding the maxillae covered the entire ridge, tuberosity and palate and extended buccally superior to the floor of the nasal fossa and maxillary sinus. For the mandibles, the entire body of the mandible was surrounded by wax and acrylic resin. The sample sites were chosen such that an equal number of maxillary and mandibular sites were included, with an equal distribution throughout the regions of the jaws. Table I displays the distribution of the sample sites.

Imaging of the jaws

The skulls were imaged in a CBCT device (Iluma, Imtek Imaging, 3M Company, St. Paul, MN) with a large FOV and a flat panel detector. The size of the detector was 19 × 24 cm and was composed of 127 μm amorphous silicon. The x-ray source focal spot size was 0.3 mm.

The skulls were placed upright on a wooden stand which was free of any metallic parts. The CBCT examinations were performed for each skull utilizing 3.8 mA, 120 kV and a 40 s exposure time, with 602 basis images acquired. The reconstruction voxel size was 0.29 mm. The volumetric data set for each skull was saved on the workstation of the CBCT device and a copy of the data set with the proprietary reformatting software of the CBCT device (Iluma-Vision 3-D (Version 1.0.2.5), Imtek Imaging, 3M Company) was stored on a CD-ROM for transfer to the laptops used in the study.

Sectioning of the skulls

After imaging, the jaws were sectioned using a band saw to obtain transverse cross-sections of the jawbones at the sites of the gutta percha markers. To ensure that the plane of the bone sections corresponded to the plane of the images, the plane of the bone sections included the inner-most portion of the gutta percha markers (crestal, buccal and lingual).

Recording of test measurements

The CBCT data sets were then analyzed on three different color liquid crystal display (LCD) monitors: Workstation (desktop): Dell Ultrasharp 2408WFP- 24" Widescreen Flat Panel Monitor (Dell Inc., Round Rock, TX); Laptop 1: Macbook- 13" glossy widescreen TFT display (Apple Inc., Cupertino, CA); Laptop 2: Dell Precision M65- 15.4" widescreen display (Dell Inc.). The specifications of the display monitors are listed in Table II. The color quality (color bit depth) for all three displays was set at 'medium' (16-bit), even though higher bit depths could have been selected with all three monitors, because 16-bit is the highest depth supported by the hardware of the CBCT device.

Each CBCT data set, along with the reformatting software, was transferred to both laptops using the same CD. Since the reformatting software required a Windows operating system, it was operated on Windows XP (Microsoft, Redmond, WA) on all the test devices, including the Macbook laptop. The CBCT reconstructed axial images were processed with the reformatting software on all three test devices to obtain transverse cross-sectional images of the jaws at the sites of the gutta percha markers (Figure 2). The transverse cross-section for each site was reformatted individually and included the crestal, buccal and lingual gutta percha markers. The thickness of the cross-sectional images used was 0.29 mm, which is the thickness used in the authors' clinical practice.

The linear measurement tool of the image processing software program was used to record the height and width dimensions of the edentulous ridges from the 24 reformatted CBCT images, yielding a total of 48 measurements.

The measurements were recorded directly from the computer monitors, in dimly lit settings, by two examiners. Both examiners were maxillofacial radiologists with 4 years experience with the CBCT device tested. The measurements were recorded twice by the first examiner and once by the second examiner.

Recording of bone measurements

The paths of measurement between the gutta percha markers were marked on the bone with a pencil and the bone measurements were recorded using a digital caliper (Mitutoyo Absolute Digimatic Caliper, Mitutoyo Corporation, Kawasaki, Japan) with 0.01

Table II. Specifications of the study monitors.

Specification	Workstation	Laptop 1	Laptop 2
Panel size	24" (60.96 cm)	13.3" (33.78 cm) (glossy widescreen) TFT display	15.4" (39.12 cm) (widescreen)
Dimensions (cm)	32.31 × 51.69	17.90 × 28.65	33.17 × 20.73
Optimal resolution	1920 × 1200	1280 × 800	1680 × 1050
Resolution used for the present study	1920 × 1200	1024 × 768	1440 × 900
Contrast ratio	1300:1 (typical)	200:1	500:1
Luminance	400 cd/m^2 (typical)	255 cd/m^2	200 cd/m^2
Pixel size	0.27 mm	Calculated pixel size: 0.26 mm	Calculated pixel size: 0.23 mm
Depth	32-Bit Color	32-Bit Color	32-Bit Color
Bit depth used for the present study	16- bit (medium)	16- bit (medium)	16- bit (medium)

mm resolution and ± 0.02 mm accuracy. The caliper was tested and found to conform to the manufacturer's standards of accuracy of ± 0.02 mm.

The wax adjacent to the measurement points was carefully removed and the tips of the caliper blades were placed on the outer surface of the bone, contacting the edge of the cut surface. All the measurements were recorded by a single observer and repeated 1 week later.

Statistics

The recorded measurements were analyzed with SPSS 19 (Statistical Package for the Social Sciences) (International Business Machines Corp. (IBM), Armonk, NY). Descriptive statistics were calculated for the differences between the measurements obtained from the images and those obtained by directly measuring the bone (the gold standard). The mean values of the two measurements recorded directly from the bone and from the CBCT images (by the first examiner) were used to calculate the error values from the images. The error was calculated as: mean test measurement from the CBCT image (first examiner) minus mean direct bone measurement. Thus, a negative error value indicated the measurement recorded from the image was smaller than the gold standard and vice versa.

The means of the *absolute* errors were then calculated for each monitor. The One-sample *t*-test (test value: zero) was used to test the statistical significance of the mean of the absolute errors of the measurements obtained with each of the three test devices. Analysis of Variance with Repeated Measures was used to test the statistical significance of the difference between the means of the absolute errors obtained by the different monitors. Statistical significance was set at a *p*-value of 0.05.

Intra- and inter-examiner reliability were evaluated with correlation testing. The two measurements

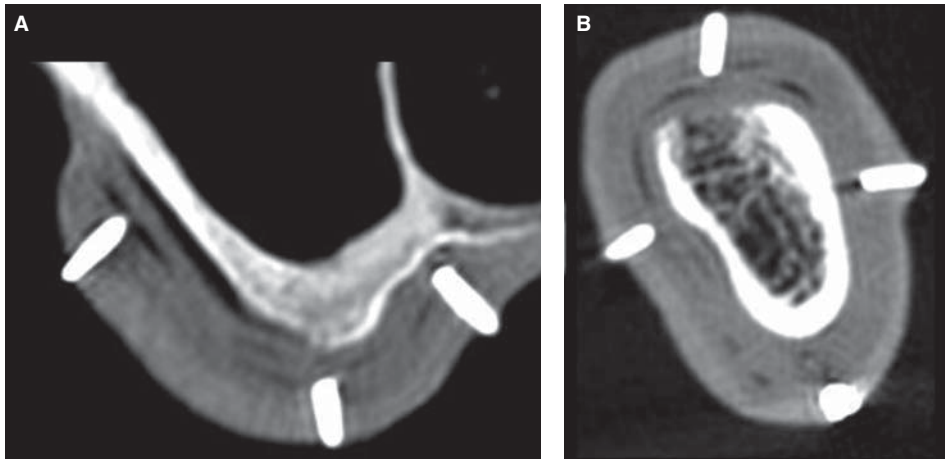

Figure 2. Sample of reformatted transverse cross-sectional images used in the study, showing the radiopaque markers used to standardize position and orientation of the sections, as well as the paths of measurement. (A) Maxillary section. (B) Mandibular section.

Table III. Intra- and inter-examiner reliability scores for the gold standard and test measurements.

Reliability	Cronbach's alpha	Inter-item correlation
Direct bone measurements (Intra-examiner)	1.000	1.000
Workstation (Intra-examiner)	0.999	0.998
Laptop 1 (Intra-examiner)	0.997	0.994
Laptop 2 (Intra-examiner)	0.999	0.998
Workstation (Inter-examiner)	0.998	0.995
Laptop 1 (Inter-examiner)	0.996	0.993
Laptop 2 (Inter-examiner)	0.997	0.994

recorded by the first examiner were used to calculate the intra-examiner reliability for the CBCT measurements. The second examiner's measurements were compared to the corresponding mean values of the first examiner's CBCT measurements for calculation of the inter-examiner reliability of the CBCT measurements.

Results

Reliability

The intra- and inter-examiner reliability scores for the gold standard and test measurements are listed in Table III. The intra- and inter-examiner reliability scores for the measurements recorded from all three test devices were all very high and ranged between 0.993–0.999, which was slightly lower than that for the gold standard intra-examiner reliability. As such there was no considerable difference in the reliability of measurements recorded using the different monitors.

Measurement error

The means of the absolute errors obtained from the workstation and Laptops 1 and 2 were 0.55 mm (95% confidence interval: 0.37–0.73 mm), 0.61 mm (95% confidence interval: 0.42–0.80 mm) and 0.68 mm (95% confidence interval: 0.46–0.87 mm), respectively. Figure 3 shows the box plots of the *absolute* measurement errors from the three display monitors. Although the absolute measurement errors from all three test devices were found to be statistically significant (p-value < 0.001), Analysis of Variance with Repeated Measures revealed no significant difference in the means of the absolute errors from the three monitors (p-value = 0.104).

Discussion

The present study aimed to investigate the effect of contrast resolution determinants of display monitors on the accuracy of implant site measurements recorded from CBCT images. The results of the present study indicate there was no significant difference in accuracy or reliability of implant site dimensions recorded from two different laptop screens and the display monitor of the CBCT device workstation, despite the considerable difference between the desktop and laptop specifications for contrast ratio and luminance.

Although six outlier values were obtained in the box plots of the measurement errors, all monitors were

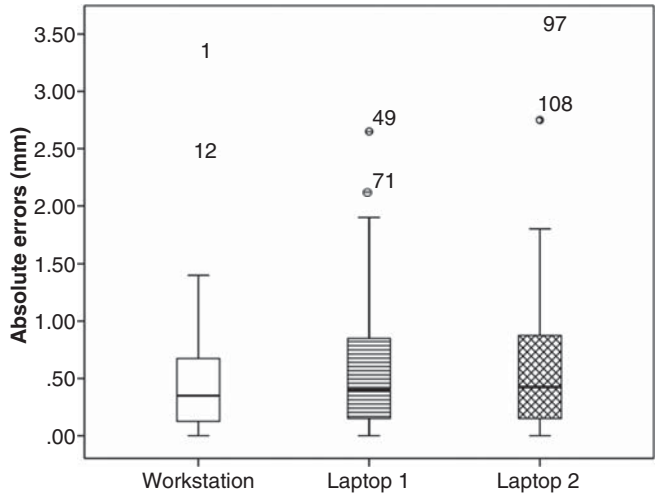

Figure 3. Box plots of the absolute measurement errors (mm) obtained from the three test devices.

affected similarly. Four of the outliers noted in the box plots (measurement errors # 1, 49, 71 and 97) can be explained by the fact that they were from height measurements at sites whose crest had been grinded, thus exposing the underlying trabecular bone and possibly making it more difficult for the observers to accurately identify the crest of the bone. The other two outliers (measurement errors # 12 and 108) were from width measurements at areas where the surface of the bone was obliquely inclined relative to the measurement path, thus slight shifts in the position or path of the measurements may have considerably affected the recorded measurements.

The contrast resolution of a monitor is mainly determined by its contrast ratio (or luminance ratio or dynamic range), which is the difference between its maximal and minimal luminance [8]. The luminance is the quantity describing the brightness of a monitor [8].

The present study's finding of similar diagnostic performance between the three display monitors is in partial agreement with the findings of Isidor et al. [17], who found a significant difference in caries diagnostic accuracy between only one monitor and two others out of a total of five monitors and in contrast with the findings of Ilgüy et al. [14], who reported better caries detectability from a medical monitor when compared to a monitor which had smaller pixel size, but lower contrast ratio and maximum luminance.

The lack of difference in diagnostic capabilities between the monitors in the present study could be attributed to the fact that measurement of ridge dimensions requires an accurate identification of a bone–soft tissue interface, which is a very high contrast landmark. Because the image of the surface of bone contrasts highly with the surrounding soft tissues, identification of such an interface may be less affected by reductions in the contrast ratio or luminance than other diagnostic tasks, such as caries detection.

Another possible explanation may be that, although the desktop monitor had a higher luminance than the laptops, with a resultant increase in the number of perceivable grey scale levels, the higher luminance may have a detrimental effect on operator performance through fatigue and the human visual adaptation response [10]. Therefore, the optimum operating luminance level may vary between users.

Another possible explanation for the lack of perceptible difference in performance of the monitors may be the fact that the examiners were free to adjust window level and width and use the zoom and pan tools. For although the Windows operating system imposes an 8-bit limit on grey scale image data sent to a display, changing the window level and width allows operators to benefit from the increased grey scale bit depth of the CBCT hardware, with improved visualization of the various grey shades [10]. The use of the zoom and pan tools by the examiners may also have masked any differences in monitor quality since use of such tools can negate the effect of pixel defects [10].

However, care must be taken when interpolating the results of the present study to images obtained with other CBCT devices or using different reconstruction voxel sizes because the amount of noise in an image is directly influenced by the CBCT device and voxel size. Noise is a higher or lower density of image voxels such that the recorded image differs from the actual image. It may also be considered as fluctuations in image density or the presence of a signal not involved in the formation of the image [8]. Noise in a digital image degrades the contrast resolution of the image and may be found in varying degrees with different CBCT devices [18]. Furthermore, decreasing the reconstruction voxel size (while using the same exposure parameters) within the same CBCT device may lead to a considerable increase in image noise [19]. It cannot be predicted how the differences in the contrast resolution of the monitors would affect implant site measurement accuracy in the presence of significant amounts of noise.

Furthermore, in the clinical situation, when CBCT data sets are transferred from the workstation to a personal computer for analysis, they may be transferred in the proprietary format for processing and analysis using the proprietary software or they may be transferred in DICOM (Digital Imaging and Communication in Medicine) format for processing with a third party software. Since the workstation analyzes proprietary images using the proprietary software, the CBCT data sets in the present study were transferred to the laptops in the proprietary format and processed and analyzed with the proprietary software in order to standardize the methodology and to avoid the introduction of confounding factors to the laptop measurements. As such, all reformatting of the sample sites and recording of the test measurements were performed using the same data sets and software on all three test devices. Therefore, the results of the present study must be applied with caution in situations where images are converted to DICOM format before processing.

The study was designed to replicate the actual clinical practice, therefore the screen resolution (number of pixels) used for the workstation display monitor was set at the optimal resolution possible, with a resultant pixel size of 0.27 mm. However, in order to standardize the study, the display resolutions selected for the laptops were not the optimal resolutions possible. Sub-optimal resolution settings were chosen for the laptops, such that the resultant pixel sizes were as near as possible to 0.27 mm, the pixel size of the workstation monitor. The attempt to standardize pixel sizes between the monitors was to reduce the number of variables under investigation

and limit the investigation to the effect of the different contrast resolution parameters on diagnostic performance. Dedicated studies investigating the effect of screen resolution on diagnostic performance for various dental diagnostic tasks are warranted, especially when CBCT data sets reconstructed with 0.2 mm or 0.1 mm voxels are used. So, in conclusion, within the limitations of the present study, no differences in the reliability or accuracy of measurements of implant site dimensions were obtained using color LCD monitors with different contrast resolution capabilities. Further standardized studies are needed to investigate the effect of screen resolution in conjunction with reconstruction voxel sizes on accuracy and reliability of implant site measurements. The effect of DICOM conversion and processing with various reformatting software programs on the accuracy and reliability of implant site measurements also needs to be investigated.

Declaration of interest: The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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