Observer preference for a dedicated medical display vs a standard screen in the detection of dental radioanatomic features

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Objective. The aim of this study was to assess observers' preference for a dentomaxillofacial dedicated medical display (MD) vs a general-purpose standard screen (SS) for in vitro and in vivo observation of normal radioanatomic features.

Study Design. The in vitro sample consisted of 2-dimensional (2-D) intraoral (n = 15), panoramic (n = 2), cephalometric (n = 2), and 3-dimensional (3-D) cone beam computed tomography (CBCT) (n = 9) data sets, acquired by utilizing commercially available skull and head-and-neck phantoms. The in vivo sample consisted of 80 radiographs (intraoral = 20; panoramic = 20; cephalometric = 20; and CBCT = 20). In vitro and in vivo data sets were both acquired by using Minray, Promax2-D, and Vistapano Ceph for 2-D images and Accuitomo, NewTom VGi evo, and Promax3-D for CBCT images. Five observers entered screen preferences when evaluating the appearance of radioanatomic structures on MD and SS.

Results. Both in vitro and in vivo assessments showed good interobserver and excellent intraobserver agreement. In vitro data suggested a significant preference for MD over SS for viewing radioanatomic features on panoramic and CBCT images, whereas MD was significantly preferred for in vivo images of all imaging modalities ($P < .001$).

Conclusions. Overall, observers preferred MD over SS for both in vitro and in vivo observation of normal radioanatomic features irrespective of the imaging modality. (Oral Surg Oral Med Oral Pathol Oral Radiol 2020;130:217−224)

Radiography is an integral component in the diagnosis and treatment planning of dentomaxillofacial pathoses.[1] Recent advances in digital dental imaging have led to a paradigm-changing revolution in dentistry. Digital intraoral (IO) and panoramic (Pan) radiography has replaced film-based radiography as the basic imaging modality for 2-dimensional (2-D) evaluation of radioanatomic structures, whereas cone beam computed tomography (CBCT) imaging has been accepted as a primary diagnostic tool for 3-dimensional (3-D) evaluation.[2] The adoption of digital radiography has eliminated the chemical developing process and reduced environmental contamination significantly.[3,4]

In addition to image postprocessing techniques and enhancement filters,[5-7] an important aspect for optimization of the digital dental workflow is related to computer display screens. According to American College of Radiology and the U.S. Food and Drug Administration, display screens can be classified as either primary or secondary screens. Primary screens are used by radiologists for interpreting medical images, whereas secondary screens are utilized by clinicians for viewing images after interpretation by a radiologist on a primary screen.[8] Image display is a vital step in the digital imaging chain, and any flaw in the display can directly affect the quality and diagnostic efficacy of an image.[9]

In medical and dental imaging, accurate radiographic representation of anatomic structures is of great importance. Over the past few years, liquid crystal display (LCD) screens have almost completely replaced cathode-ray tubes (CRT) in radiology.[8] The key display characteristics of screens, such as noise, resolution, luminance response and uniformity, pixel size, geometric distortion, and display reflection, impact image quality, thereby affecting observer performance.[8,10] The utilization of dedicated medical display (MD) screens that optimize these characteristics has been well documented and has shown improved diagnostic and clinical performance in observing breast cancer on screening mammograms and lung nodules on chest radiographs.[11,12]

MD screens are available in dentomaxillofacial imaging. Dentally configured MDs have been engineered on the basis of the resolution and gray scale of

Statement of Clinical Relevance

The quality of image displays in dentomaxillofacial radiology may affect the efficacy of radiographic interpretation, diagnosis, and treatment planning. Dedicated medical display devices may improve diagnostic efficacy compared with standard screens.

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dental radiographs, unlike normal MDs that are configured on the basis of medical radiology images.[13-15] However, it is questionable whether specifically configured "dental" settings on an MD are actually beneficial in such tasks as detection of radioanatomic structures and diagnosis of disease. There is lack of scientific evidence to support the notion that use of these monitors improves efficacy in observing radioanatomic features compared with general purpose standard screens (SS).

Therefore, the aim of the present study was to assess observers' preference for a dentomaxillofacial dedicated MD vs a general-purpose SS for in vitro and in vivo observation of normal radioanatomic features on 2-D and 3-D images.

MATERIALS AND METHODS

Ethical approval

This retrospective study was conducted in compliance with the tenets of the World Medical Association Declaration of Helsinki on medical research. Ethical approval was acquired from the Medical Ethics Committee of University Hospitals, KU Leuven, Leuven, Belgium (Reference No. S59247). Patient-specific images and information were anonymized. In vitro and in vivo samples of radiographs were collected for this study. An in vitro sample was evaluated because it allowed image analysis without patient motion artifacts, whereas the in vivo images represented actual clinical conditions. Inclusion criteria were good quality of images and the presence of sharply delineated normal radioanatomic features. Exclusion criteria were presence of any metal, restoration, and/or motion artefacts affecting image quality

In vitro sample

A commercially available skull phantom, covered with Mix D soft tissue simulation,[16] was placed in a Minray IO radiographic unit (Soredex, Tuusala, Finland) operating at 65 kVp and 7 mA for acquiring IO radiographs with use of the paralleling technique (n = 15). A full head-and-neck Rando phantom (Alderson-Rando, Long Beach, CA) with soft tissue simulation was placed in 2 radiographic devices, the Promax 2-D (Planmeca, Helsinki, Finland) and the Vistapano Ceph (Durr Dental, Bittigheim-Bissingen, Germany) to generate one Pan and one cephalometric (Ceph) radiograph with each device (n = 2 Pan and n = 2 Ceph). Three CBCT devices, 3-D Accuitomo 170 (J. Morita, Kyoto, Japan), NewTom VGi evo (QR, Verona, Italy), and Promax 3-D Max (Planmeca, Helsinki, Finland), with 9 overall protocols consisting of combinations of fields of view (FOVs), exposure doses, and voxel sizes, were utilized for generating 3-D images of the phantom head and neck.

In vivo sample

A retrospective sample of radiographs from 80 patients referred to the dentomaxillofacial radiology center (University Hospitals Leuven, Belgium) for 2-D and 3-D diagnostic imaging was included for the in vivo evaluation. Radioanatomic features were observed on IO (n = 20), Pan (n = 20), Ceph (n = 20) radiographs and on the axial, sagittal, and coronal views of 20 randomly selected CBCT scans acquired by using the same acquisition devices.

For both in vitro and in vivo images, detection of radioanatomic features on the IO, Pan, and CBCT radiographs included the cementoenamel junction (CEJ); pulpal canal (PC) structure; apical third of the pulp canal (APC; defined as the apical one-third of the canal between the CEJ and root apex); periodontal ligament space; lamina dura; alveolar crest (AC); and trabecular structure. On the Ceph radiographs, point A, point B, and soft tissue were observed (Table I). Radioanatomic features were observed around each tooth on all 2-D radiographs. The 9 in vitro CBCT image data sets, corresponding to the 9 protocols, were evaluated on the axial, sagittal, and coronal planes around 4 maxillary teeth, that is, left and right central incisors and canines (9 protocols × 4 teeth = 36 images); and 3 mandibular teeth, that is, the left first premolar, right second premolar, and right first molar (9 protocols × 3 teeth = 27 images). The CBCT units and the 9 protocols used are presented in Table II.

Display screens

The first screen was a dedicated MD Barco MDRC-2221; (Barco, Kortrijk, Belgium), calibrated in the DICOM (Digital Imaging and Communications in Medicine) format with interior compensation light and frontal sensor that overcame inherent instability of backlight lamps. The second screen was a general-purpose SS Dell U2415 b UltraSharp Widescreen LCD (Dell Inc., Round Rock, TX). Table III describes the

Table I. Normal radioanatomic structures

Type of modality	*Anatomic features*
Intraoral Panoramic	Cementoenamel junction
Cone beam computed tomography	(CEJ)
	Pulpal canal (PC) structure
	Apical third of pulp canal (APC)
	Periodontal ligament space (PLS)
	Lamina dura (LD)
	Alveolar crest (AC)
	Trabecular structure (TS)
Cephalometric	Point A
	Point B
	Soft tissue

Table II. CBCT acquisition devices and protocols

CBCT	*FOV*	*Voxel Size (μm)*
3-D Accuitomo 170 (J. Morita, Kyoto, Japan)	4 × 4 cm	80
	6 × 6 cm	125
	8 × 8 cm	160
NewTom VGi evo (QR, Verona, Italy)	8 × 5 cm RS	200
	8 × 8 cm RS	200
	8 × 8 cm RECO	200
Promax 3-D Max (Planmeca, Helsinki, Finland)	10 × 9 cm ULD LD	400
	10 × 9 cm ULD HD	150
	10 × 9 cm NHD	150

CBCT, cone beam computed tomography; *FOV,* field of view; *NHD,* normal high definition; *RECO,* regular economic quality; *RS,* regular standard quality; *ULD LD,* ultra-low dose low definition; *ULD HD,* ultra-low dose high definition.

specifications of the screens. The specified MD and SS were selected because these were the most commonly utilized primary screens in our radiology clinics for performing radiologic tasks. The main visual differences between the screens were related to size and contrast. However, the observers were unaware which screen was an MD or an SS based on size. The viewing angles for both screens were the same. Luminance for both screens was set at maximum to achieve optimal contrast ratio setting. Images were analyzed in a dimmed room at a 60 cm viewing distance.

Observations

Five independent blinded observers evaluated the images after initial training and calibration. The 5 observers were all specialists in oral and maxillofacial radiology and had a minimum of 5 years of experience in the field. A duplicated setup of the screens was configured to evaluate the same structures on both screens at the same time. The screen's contours and brand logos were hidden within a wall-mounted frame to blind the observers during image evaluation, and both screens were assigned separate numbers randomly for each observer. The images were preopened before being observed to further blind the observers to the type of screen.

Table III. Specifications of screens

Parameters	*Medical display*	*Standard screen*
Display size, diagonal	54.1 cm (21.3 inch)	61.1 cm (24.1 inch)
Technology	Thin-film transistor	In-plane switching
Resolution	1600 × 1200	1920 × 1200
Pixels per inch	94	132
Pixel pitch, mm	0.27 mm	0.27 mm
Maximum brightness, candela/m^2	440 cd/m^2; typical	300 cd/m^2 (typical)
Default contrast ratio	1500:1 typical	1000:1 (typical)
Response time	20 ms	6 ms

Subjective visualization scale

The observers were asked to evaluate each of the radioanatomic features on each imaging modality on each screen and indicate which screen was preferred for each feature. A 3-point ordinal scale (1−3) was used to evaluate the preference of the observers with 1 = MD preferred; 2 = MD and SS equally preferred; and 3 = SS preferred.

All observers performed the assessment twice separately with a 1-week interval to allow for calculation of interobserver and intraobserver agreements. The assigned screen numbers and their placements were also randomized after 1 week.

Statistical analysis

Data were analyzed by using SPSS Statistics for Windows, version 22.0 (IBM Corp., Armonk, NY). The interobserver and intraobserver agreements of paired observers were calculated for each type of radiograph in the in vitro and in vivo data sets by using the kappa test, which was classified as follows: poor (< 0.20), fair (0.21−0.40), moderate (0.41−0.60), good (0.61−0.80), and excellent (0.81−1.00).[17] All observer preferences were expressed as percentages by pooling the responses of observers for the detection of each anatomic feature related to both in vitro (IO = 15; Pan = 2; Ceph = 2; CBCT = 9) and in vivo (IO = 20; Pan = 20; Ceph = 20; CBCT = 20) data sets. The significance for the preference of MD in radioanatomic feature detection was calculated by using Pearson's χ^2 test. A value of $P < .001$ was considered statistically significant.

RESULTS

Both in vitro and in vivo assessments showed overall good interobserver agreement ($\kappa \geq 0.80$) and excellent intraobserver agreement ($\kappa \geq 0.93$) without significant differences among the observers.

In vitro assessment

Figure 1 illustrates the percentages of observers' preference for detecting radioanatomic features on IO radiographs, with greater preference for MD compared with SS for 5 of the 7 radioanatomic features. PC and APC exhibited equal preference for MD and SS in all evaluations. SS was not preferred over MD for any feature. On Pan radiographs, the AC scored 2 on the ordinal scale (MD and SS equally preferred) for 100% observations. CEJ and PC showed no more than 14% observer preference in favor of MD (Figure 2). Similar to the data for IO, however, SS was not preferred over MD for any of the landmarks. Point A was the only anatomic landmark on Ceph radiographs that showed a slight observer preference for MD, whereas point B

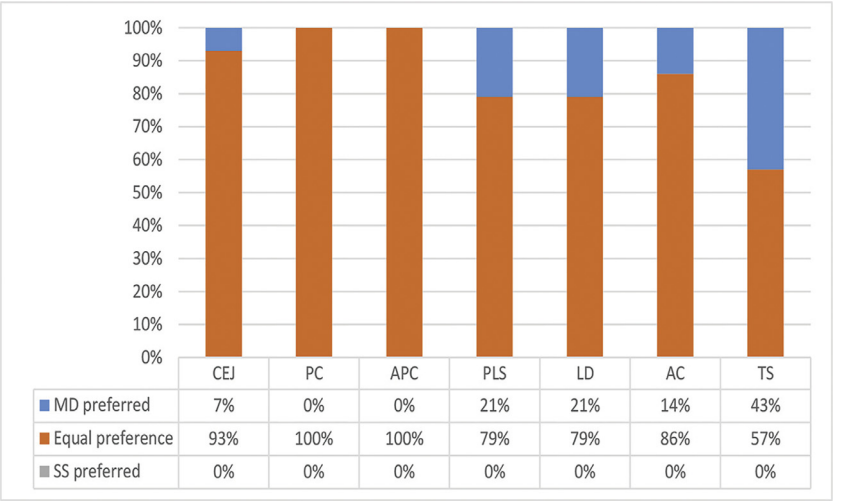

Fig. 1. In vitro radioanatomic feature detection on intraoral radiographs. *AC,* alveolar crest; *APC,* apical pulp canal; *CEJ,* cementoenamel junction; *LD,* lamina dura; *MD,* medical display; *PC,* pulp canal; *PLS,* periodontal ligament space; *SS,* standard screen; *TS,* trabecular structure.

and soft tissue were equally preferred by all observers; no observers preferred SS over MD (Figure 3).

Figure 4 illustrates the results of the evaluation of the CBCT scans overall for the 7 radioanatomic features. NewTom VGi evo (QR, Verona, Italy), Regular Standard (FOV: 8 × 5 cm; voxel size: 200 μm) showed the lowest observer preference (8%) in favor of MD, whereas Promax 3-D Max (Planmeca, Helsinki, Finland) ultra-low-dose low definition (FOV: 10 × 9 cm; voxel size: 400 μm) showed highest preference at 42% (see Figure 4). Overall, the Newtom VGI evo CBCT device (QR) received the lowest preference for MD regardless of FOV and voxel size compared with the other 2 CBCT scanners. No observations in favor of SS were detected.

The combined observations showed no significant preference of viewing anatomic features on MD vs SS for IO ($P = .064$) and Ceph radiographs ($P = .387$), but observers significantly preferred MD over SS for viewing features on Pan radiographs and CBCT images ($P \leq .001$), as shown in Table IV.

In vivo assessment

Figures 5 and 6 illustrate the preferences of observers for detecting radioanatomic features on IO and Pan radiographs, respectively. Preference for MD was

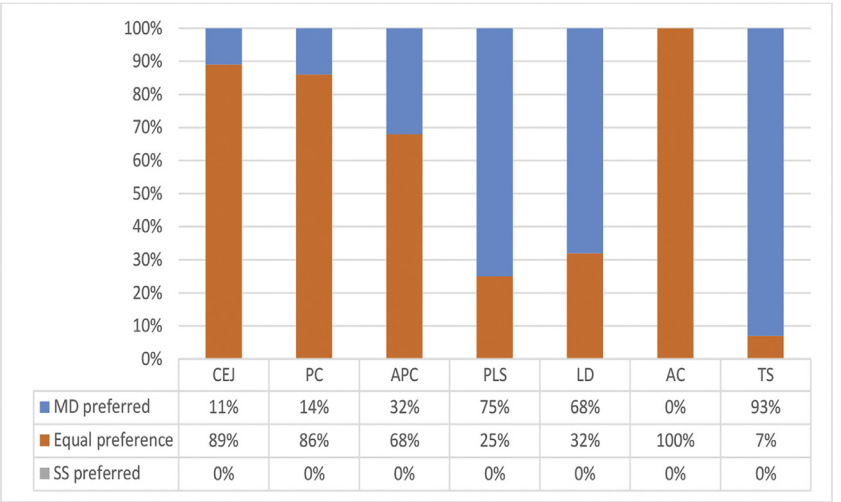

Fig. 2. In vitro radioanatomic feature detection on panoramic radiographs. *AC,* alveolar crest; *APC,* apical pulp canal; *CEJ,* cementoenamel junction; *LD,* lamina dura; *MD,* medical display; *PC,* pulp canal; *PLS,* periodontal ligament space; *SS,* standard screen; *TS,* trabecular structure.

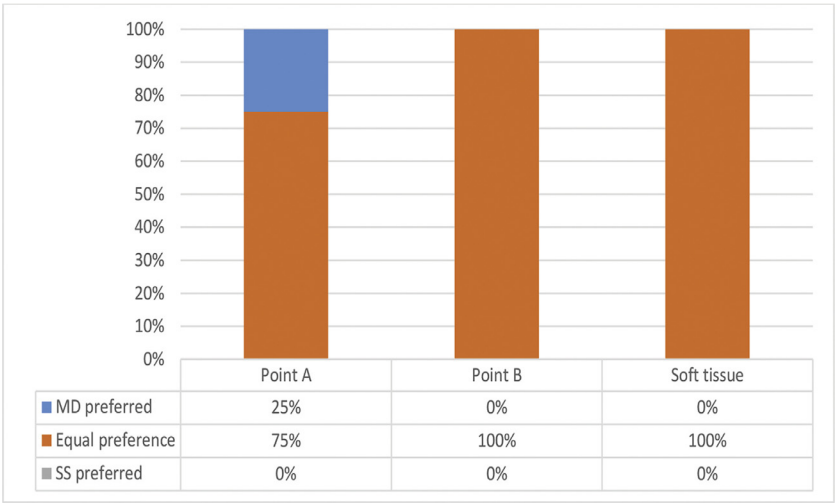

Fig. 3. In vitro radioanatomic feature detection on cephalometric radiographs. *MD,* medical display; *SS,* standard screen.

much greater than that for SS for all features in the IO series, with no observers preferring SS. Similar results were noted for the radioanatomic features on Pan radiographs, with the exception of the AC, for which only 5% expressed a preference for MD over SS. On Ceph radiographs, the observers preferred SS only in 2% of the data for detecting point A (Figure 7). The observers did not show a preference for SS for any of the CBCT images (Figure 8). Overall, a significant observer preference ($P \leq .001$) was seen in favor of MD for detection of anatomic features with all imaging modalities (see Table IV).

DISCUSSION

The virtual imaging chain consists of 4 vital phases: raw data acquisition, data processing, electronic display, and visual interpretation by a viewer. With recent advancements in digital imaging, the influence of a display screen for increasing diagnostic efficacy, as evaluated through observer preference in detection of radioanatomic features, is of utmost importance.[9] In the present study, in vitro data showed significant observer preference in favor of MD over SS when viewing anatomic structures on Pan radiographs and CBCT images. Analysis of in vivo radiographs revealed a significantly greater preference for MD over SS for all imaging modalities. In a large number of cases, both MD and SS were equally preferred, and in the rest, MD was given preference over SS by the observers. For the in vivo detection of the CEJ on IO radiographs, the observers showed the highest preference for detection with MD (88%). Even though the

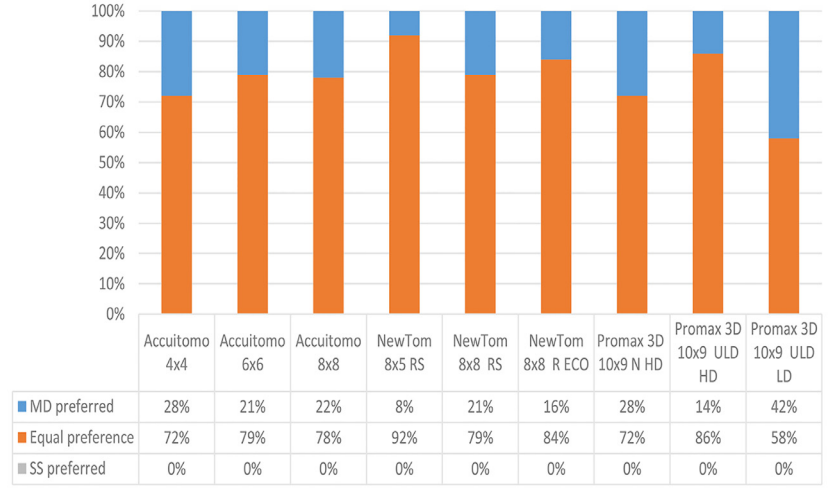

Fig. 4. In vitro radioanatomic feature detection on CBCT images with different CBCT devices and protocols. *MD,* medical display; *NHD,* normal high definition; *R ECO,* regular economic quality; *RS,* regular standard quality; *SS,* standard screen; *ULD HD,* ultra-low dose high definition; *ULD LD,* ultra-low dose low definition.

Table IV. Overall screen preference for radioanatomic feature detection with all imaging modalities

Radiograph	*In vitro screen preference*			*P value*	*In vivo screen preference*			*P value*
	MD	*EQ*	*SS*		*MD*	*EQ*	*SS*	
Intraoral	15%	85%	0%	.064	62%	38%	0%	< **.001**
Panoramic	42%	58%	0%	< **.001**	43%	57%	0%	< **.001**
Cephalometric	8%	92%	0%	.387	32%	67%	1%	< **.001**
CBCT	22%	78%	0%	< **.001**	54%	46%	0%	< **.001**

CBCT, cone beam computed tomography; *EQ,* equal preference; *MD,* medical display; *SS,* standard screen.
***P* value < .001** = Significant preference in favor of medical display for detection of radioanatomic features.

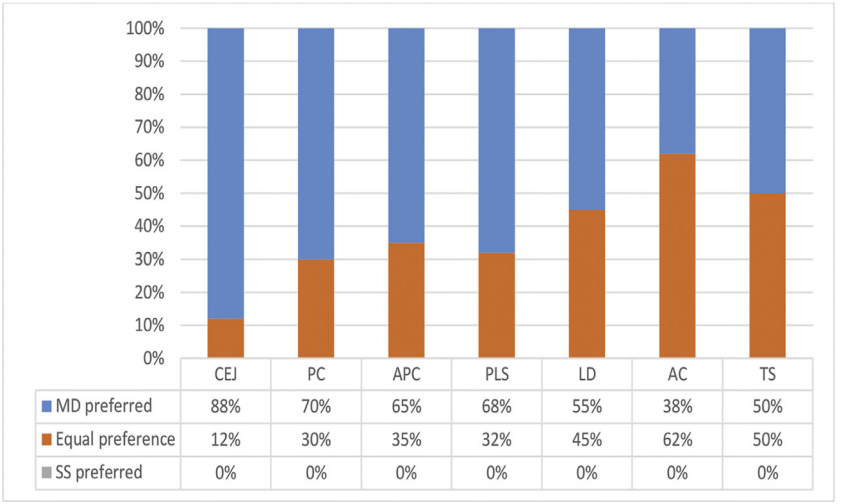

Fig. 5. In vivo radioanatomic feature detection on intraoral radiographs. *AC,* alveolar crest; *APC,* apical pulp canal; *CEJ,* cementoenamel junction; *LD,* lamina dura; *MD,* medical display; *PC,* pulp canal; *PLS,* periodontal ligament space; *SS,* standard screen; *TS,* trabecular structure.

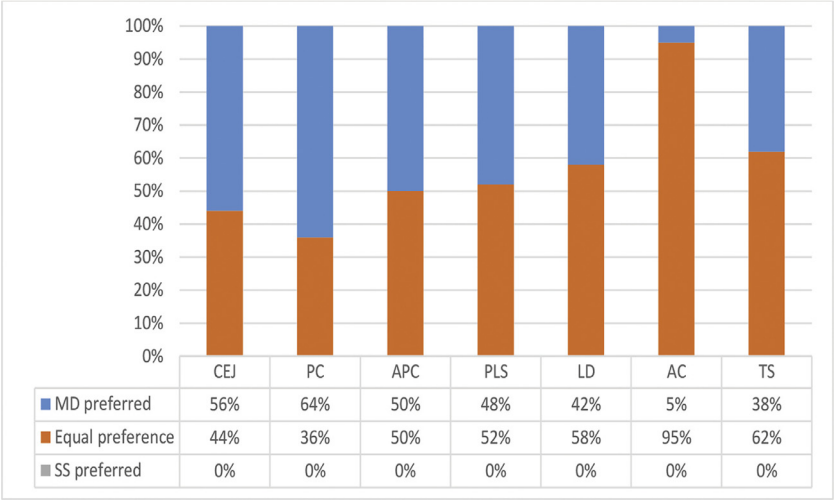

Fig. 6. In vivo radioanatomic feature detection on panoramic radiographs. *AC,* alveolar crest; *APC,* apical pulp canal; *CEJ,* cementoenamel junction; *LD,* lamina dura; *MD,* medical display; *PC,* pulp canal; *PLS,* periodontal ligament space; *SS,* standard screen; *TS,* trabecular structure.

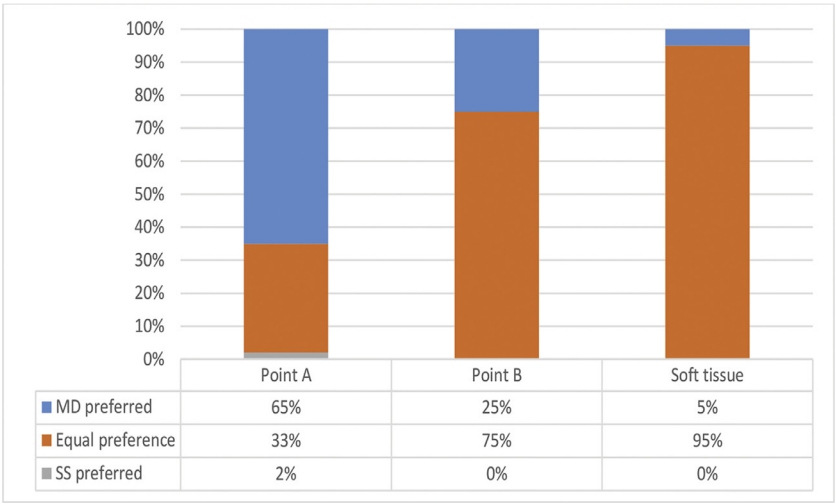

Fig. 7. In vivo radioanatomic feature detection on cephalometric radiographs. *MD,* medical display; *SS,* standard screen.

observers preferred both screens equally for the identification of the AC region on Pan radiographs (95%), the performance of the observers when using SS might be reduced as teeth often hide the crestal area because of normal distortion related to the technique.[18] According to Kallio-Pulkkinen et al., detection of anatomic structures on Pan radiographs relied on the experience of the observers, with the more experienced observers detecting radioanatomic features on both consumer-grade and dedicated MDs without significant difference.[19] In contrast, all of the experienced observers in our study preferred detection of radioanatomic feature on MD over SS with preinstalled dental settings.

The analysis of Ceph images mainly showed a difference in preference for detecting point A. However, observers considered MD as the preferred screen in assessing both in vitro and in vivo images. Because point A is the most difficult landmark to detect,[20] MD can be useful in this situation, especially for assessing landmarks on Ceph radiographs with low resolution. On the basis of our findings, high feature detection became more dependent on the CBCT device and its capacity to acquire, process, and show images on the screen. In contrast, CBCT images with low-dose protocols, lower resolution, and greater voxel size provided improved detection of radioanatomic features by the observers on MD. This might be related to the improved luminance stabilization and the special DICOM format of MD for viewing the images.[8] The increased contrast ratio and the presence of a unique front consistency sensor in MD also might have resulted in observer preference in favor of MD

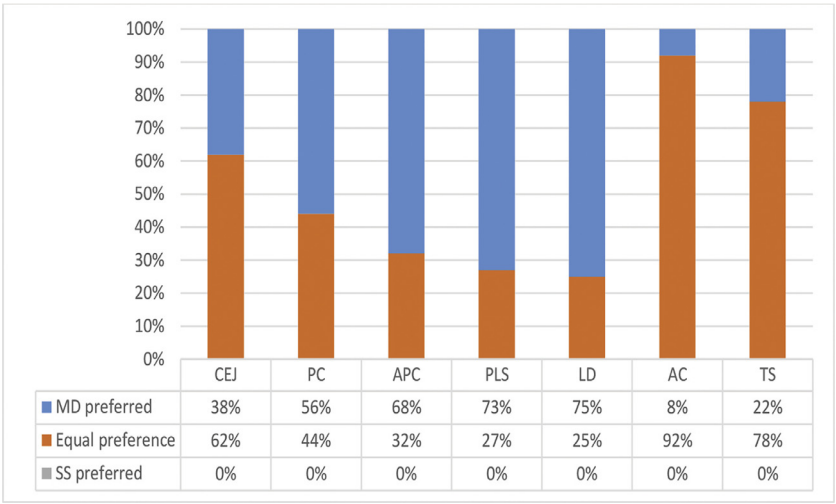

Fig. 8. In vivo radioanatomic feature detection on CBCT images. *AC,* alveolar crest; *APC,* apical pulp canal; *CEJ,* cementoenamel junction; *LD,* lamina dura; *MD,* medical display; *PC,* pulp canal; *PLS,* periodontal ligament space; *SS,* standard screen; *TS,* trabecular structure.

compared with SS. SS had a higher pixel pitch and response time, but these parameters had no effect on the preference of the observers.

In previous studies, observers showed improved performance when utilizing MD for the detection of lung nodules and other complex medical anatomic structures.[12] However, most dental radiology studies showed better, but not significant, improvement in performance for measuring working length during endodontic treatment, detection of caries, and vertical root fractures when using display devices of varying quality.[21-24] In contrast, our study showed significant increase in observer preference for MD because we focused on different radioanatomic features instead of pathologic lesions. Additionally, no studies were available in the literature comparing screen preferences for detecting multiple dental radioanatomic features. We believe our study fills the gap related to observers' preference of MD for detecting dental radioanatomic features.

The main limitation of our study was related to the number of screens included. Further studies should be conducted to compare the effectiveness of multiple dedicated MD and SS in detection of common pathologic conditions to observe whether MD with dentomaxillofacial settings can improve diagnostic efficacy. Also, the effects of medical monitor technology, such as in-plane switching and thin-film transistors, should also be investigated to assess which technology offers improved image preference with optimal quality in dentomaxillofacial radiology.

CONCLUSIONS

Overall, observers preferred the MD monitor over the standard monitor for both in vitro and in vivo observation of normal dental radioanatomic features irrespective of the imaging modality.

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