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The influence of image display systems on observers' preference for visualizing subtle dental radiographic abnormalities

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Objective. The objectives of this study were to assess observers' preference for standard screens (SSs) or medical displays (MDs) in visualizing difficult-to-diagnose radiographic dental abnormalities and their preference for dental filter tools when utilized with MD systems.

Study Design. A retrospective data set of 60 in vivo radiographs consisting of intraoral (n = 20), panoramic (n = 20), and cone beam computed tomography (n = 20) images was created. Three image display monitors, including an SS, an MD, and an MD with 3 dental filter configurations (bone−low density enhancement filter, tooth−high density enhancement filter, and a combined filter representing regular MD), were utilized to assess 4 observers' monitor preferences in detecting radiographically subtle dental abnormalities. The data were analyzed by using binomial distribution. A P value $\leq$.05 was considered statistically significant.

Results. Although observers expressed preference for MD for visualizing some abnormalities when examining intraoral and panoramic radiographs, MD was not preferred for detection of any abnormalities with cone beam computed tomography. There were no significant differences in preference for SS or MD overall ($P \geq .2024$). Observers expressed significant preference for the filters in visualizing all but 2 abnormalities ($P \leq .0252$).

Conclusions. The use of MD monitors enabled with dental filter tools may be preferred for visualizing certain subtle abnormalities. (Oral Surg Oral Med Oral Pathol Oral Radiol 2020;000:4539)

Digital imaging is an essential element in oral and maxillofacial diagnosis. All parts of the radiodiagnostic imaging chain must function optimally, including the display monitor.[1] Several guidelines have been proposed in medical radiology to ensure the optimization of display monitors and presentation of radiographs with grayscale calibration in accordance with Digital Imaging and Communication in Medicine (DICOM) Part 14: Grayscale Standard Display Function (GSDF).[2,3] Nevertheless, no comprehensive guidelines exist in relation to the application of display monitors in dentomaxillofacial radiology.[4]

In an attempt to improve the digital radiodiagnostic imaging chain, general-purpose standard screens (SSs) are being replaced with dedicated medical displays (MDs), which have the ability to depict minute changes in grayscale values on radiographs.[5] The SS has been considered sufficient for primary diagnosis based on medical imaging standards.[6] Nevertheless, these display monitors have a risk of luminance and contrast ratio degradation over time that can lead to misinterpretation of the radiographic data; consequently, these monitors require quality assurance assessment on a regular basis.[7,8] In contrast, the quality control and self-calibration ability of the MD overcome these limitations. The role of DICOM-calibrated medical display monitors is of vital importance, especially for improving the diagnostic performance in dentistry, where detection using non-DICOM-calibrated SSs and/or image enhancement algorithms incorporated in the acquisition devices' software programs is deemed insufficient.[9-11] In the dentomaxillofacial field, controversy persists regarding the capability of a monitor to improve the observers' diagnostic outcomes. Studies have suggested that an MD enhances the ability of dentists to visualize and make correct diagnoses of dental abnormalities compared to an SS, resulting in improved diagnostic efficacy,[12,13] whereas other research has revealed no significant differences between SS and MD in relation to observer

Statement of Clinical Relevance

The use of medical imaging displays combined with dental filter tools instead of standard screens may facilitate the identification of subtle abnormalities in some image types. This may improve the efficacy of detecting and diagnosing these conditions, improving patient care.

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preference.[14,15] Most of the aforementioned studies have limited clinical value because they failed to provide the impact on observer preference in relation to multiple dental abnormalities. They were focused instead on single dental anomalies acquired with only one type of imaging modality.[12,16-18] Additionally, no evidence was found related to the diagnostic preference for MDs incorporated with dental filters. Because dentomaxillofacial anatomic structures have different x-ray absorption characteristics, each structure has its own characteristic range of pixel values.[19] This principle has been utilized to design filters that can enhance visibility of specific structures. These state-of-the-art MDs with dental configurations apply significant amounts of image processing in real time to ensure that image quality and visualization are optimal at any moment.

To the best of our knowledge, no studies are available on the preference of observers for radiographic display monitors when examining radiographically challenging dental abnormalities acquired with different imaging modalities or whether a dentally configured MD further enhances the diagnostic efficacy compared to a regular MD. Therefore, this study was conducted to assess observers' preference for display devices when visualizing difficult-to-diagnose radiographic dental abnormalities utilizing 3 image display monitors. The first aim of the study was to assess whether observers preferred SS or MD when visualizing subtle radiographic dental abnormalities. The second aim was to observe whether an MD with a dental filter tool further enhanced the observers' preference compared to the regular MD. The null hypotheses stated that there would be no differences in preference for MD over SS or in MD with dental filter tools over regular MD. The alternative hypotheses stated that the observers would prefer an MD over an SS and would prefer an MD with dental filter tools over a regular MD for this task.

MATERIALS AND METHODS

This retrospective study was conducted in compliance with the World Medical Association Declaration of Helsinki on medical research. Ethics approval was acquired from the Medical Ethics Committee of University Hospitals, KU Leuven, Leuven, Belgium (Reference No. S59247). Informed consent was not required because patient information was anonymized.

Inclusion criteria for the radiographs consisted of acceptable image quality and the presence of subtle, difficult-to-diagnose radiographic dental abnormalities on intraoral, panoramic, and cone beam computed tomography (CBCT) images. The abnormalities consisted of periodontal ligament space widening (PLSW), incipient caries (IC), dens in dente (DD), granuloma (G), fusion (F), root fracture (RF), external root resorption (ERR), pulp stone (PS), and additional root canals (ARC). Images with metal and/or motion artefacts were excluded. Based on the inclusion and exclusion criteria, a retrospective data set of 60 in vivo images with previously diagnosed dental abnormalities, consisting of intraoral (n = 20), panoramic (n = 20), and CBCT (n = 20) images, was collected from the database of the Dentomaxillofacial Radiology Center, University Hospitals Leuven, Leuven, Belgium.

The intraoral and panoramic radiographs were acquired with Promax 2D (Planmeca, Helsinki, Finland) and Vistapano Ceph (Durr Dental, Bittigheim-Bissingen, Germany) units, respectively. The CBCT devices included 3D Accuitomo170 (J. Morita, Kyoto, Japan), NewTomVGI evo (QR, Verona, Italy), and Promax 3D Max (Planmeca), with a field of view ranging from 4 × 6 cm to 10 × 9 cm, tube potential of 80 to 90 kV, and voxel sizes ranging from 0.125 to 0.250 mm^3. The CBCT images were evaluated only in sagittal, coronal, and axial views.

The numbers of abnormalities acquired with each imaging modality are listed in Table I. Only certain types of abnormalities were examined in each type of image. IC in the list of abnormalities was defined as caries that penetrated only halfway through the enamel structure.

Three display monitors were involved in the study. The first monitor was a general-purpose SS (Dell U2415b UltraSharp 24-in Widescreen LCD, Dell, Round Rock, TX) with resolution of 1920 × 1200, maximum brightness of 300 cd/m^2, and contrast ratio of 1000:1. This screen is utilized in most of our hospital clinics for diagnostic purposes. The second monitor was a DICOM-compatible MD (Barco MDRC-2223 23-in diagonally viewable size LCD, Barco, Kortrijk, Belgium) with resolution of 1920 × 1080, maximum

Table I. Distribution of dental abnormalities acquired with each imaging modality and diagnosed by consecutive visualization on a standard screen and a medical display

Abnormality	*Intraoral*	*Panoramic*	*CBCT*	*Total*
Periodontal ligament space widening	18	—	—	18
Incipient caries	15	8	—	23
Dens in dente	6	8	12	26
Granuloma	3	—	—	3
Fusion	3	2	—	5
Root fracture	3	4	11	18
External root resorption	—	6	4	10
Pulp stone	—	9	—	9
Additional root canal	—	6	6	12
Total	48	43	33	124

CBCT, cone beam computed tomography.

brightness of 440 cd/m^2, and contrast ratio of 1500:1. The third monitor was also a Barco MDRC-2223 with the same specifications as mentioned above. However, unlike the regular MD, a dentally configured filter tool was incorporated into this display. The dental tool consisted of 3 configurations, referred to as bone−low density enhancement filter (B-LDEF), tooth−high density enhancement filter (T-HDEF), and a combined filter. The combined filter allowed the user to view the image as originally seen on the regular MD without the dental configuration. The filtering tool was specifically compatible with the display utilized in the study. It allowed the user to change the configuration of the display to enhance the quality of dental structures based on their radiodensity. Both bone and tooth filters functioned by constantly processing the image to ensure that the display was compliant with DICOM GSDF and that subtle image features could be detected. Image processing did not alter the contents of the dental images. Instead, the processing was applied to ensure that information present in the images was displayed in the optimal way for the observer. The DICOM GSDF aims to optimize overall visibility of the information present in a dental image and is not designed to specifically enhance visibility of selected structures. As such, the filters were an extension and further refinement that allowed selective enhancement of specific structures. Luminance for all screens was set at maximum for consistency and images were analyzed in a dimmed room at a 60-cm viewing distance.

Four observers (2 radiologists, 1 pediatric dentist, and 1 oral surgeon) with a minimum experience of 5 years recorded their display monitor preference for detecting the abnormalities, which had been previously diagnosed radiographically by the consensus of 2 board-certified oral and maxillofacial radiologists, each with more than 20 years of experience, who diagnosed the abnormalities on SS and MD consecutively. Consensus of the 2 radiologists was obtained for all abnormalities in establishing the final diagnosis. The abnormalities were subtle and difficult to visualize, so an initial training and calibration session was carried out utilizing a 2-fold procedure for each abnormality (training cases together with the expert radiologist, training cases separately discussed with the expert radiologist). The abnormalities were defined before assessment and explained to the observers. If the abnormality was detected, the observers indicated which screen they preferred for visualizing the abnormality. In the case of the large field of view images (panoramic and CBCT), observers were provided with the region of interest where the abnormalities existed. During the evaluation period the observers were additionally provided with a list of the abnormalities that existed in the specified region.

On the first day, a duplicated screen setup was organized to diagnose and visualize abnormalities with the SS and the regular MD. On the second day the observers visualized similar abnormalities with all 3 dental tool filters separately on 3 MDs, to observe which filter offered the best visualization of the abnormalities. To blind the observers to the type of screen, the logos and contours of the screens were hidden within a wall-mounted frame. Observers were also blinded to the type of filter (bone, tooth, and combination) by renaming the filter tabs with numbers.

A scoring criterion was established on a scale of 1 to 3 by recording the observers' preferences for visualizing the abnormalities on SS compared to MD, where 1 indicated SS preferred, 2 indicated equal preference, and 3 indicated MD preferred. The scoring criteria for the screens with each dental filter tool was as follows: 1 indicated B-LDEF preferred, 2 indicated combined filter preferred, and 3 indicated T-HDEF preferred. All observers performed the rating twice with a 1-week interval to allow calculation of intra- and interobserver agreement. The monitors were randomly placed and allocated at each interval.

Statistical analysis

Data were analyzed using IBM SPSS Statistics for Windows, Version 22.0 (IBM Corporation, Armonk, NY). The preferences of the observers were pooled together and were represented as percentages. In relation to the preference between the 2 types of displays, binomial distribution was carried out to test whether MD was preferred over SS. For the dental filter tool, binomial distribution was analyzed for each filter to assess the observers' preferences in detecting each abnormality. The intraobserver and interobserver agreement for each pair of observers and each radiographic modality were calculated using the kappa test, with results classified as follows: poor (<0.20), fair (0:21 to 0:40), moderate (0.41-0.60), good (0.61-0.80), and excellent (0.81-1.00) agreement.[20] A P value $\leq$.05 was considered statistically significant.

RESULTS

Figures 1A to 1C illustrate the preference for SS and MD in relation to the type of imaging modality for detecting the abnormalities. A comparison of observers' preferences when examining intraoral radiographs (Figure 1A) revealed no preference in favor of SS. A higher percentage of preference was recorded for MD in the detection of PLSW (60%, P = .2517) and IC (52.4%, P = .5122) on intraoral radiographs, whereas equal preference predominated for the other abnormalities. Based on panoramic radiography (Figure 1B), a higher preference for MD was observed only for the detection of DD (50%, P = .6128), ERR (66.7%, P = .5720), and PS (58.3%. P = .3872), whereas equal preference was found to be as high or higher for the

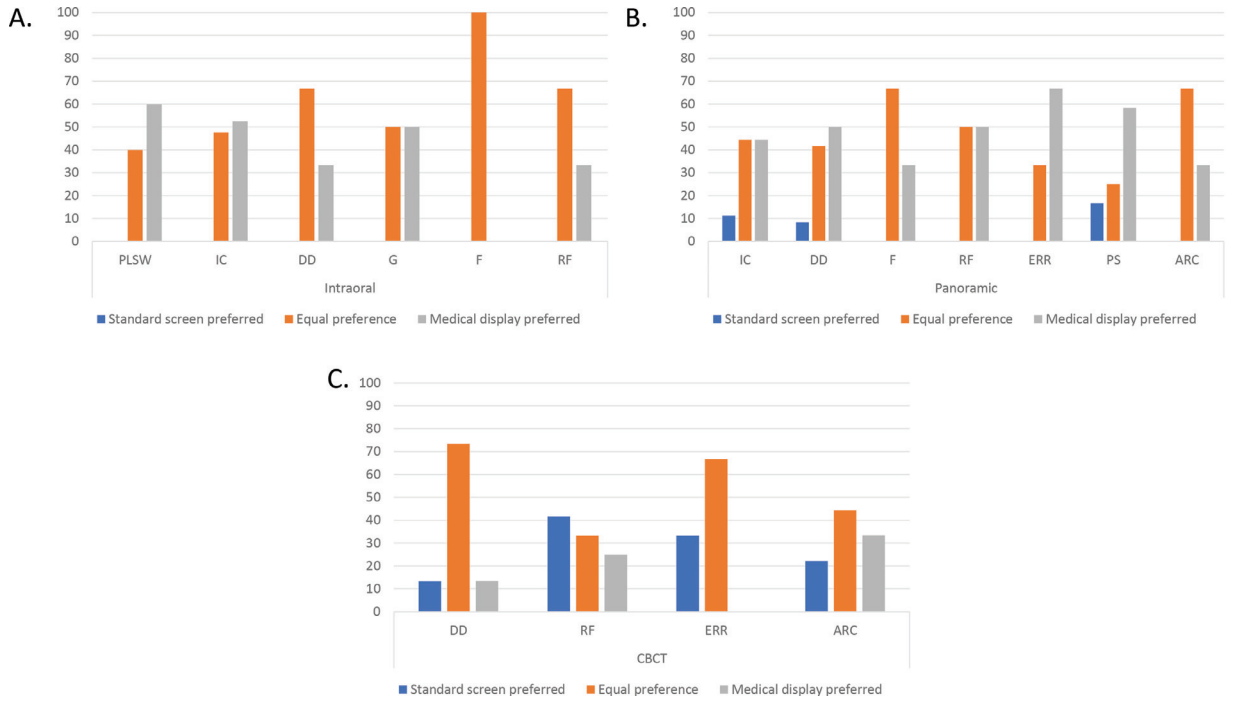


Fig. 1. Percentage of observers' preference for visualizing abnormalities with standard screen and medical display: **(A)** intraoral radiographs; **(B)** panoramic radiographs; and **(C)** cone beam computed tomography. *PLSW*, periodontal ligament space widening; *IC*, incipient caries; *DD*, dens in dente; *G*, granuloma; *F*, fusion; *RF*, root fracture; *ERR*, external root resorption; *PS*, pulp stone; *ARC*, additional root canals.

detection of the rest of the abnormalities. With the CBCT images (Figure 1C), observers showed a higher preference for SS in the detection of RF (41.7%, $P = .9807$). In contrast to intraoral and panoramic radiographs, MD was not preferred for detection of any of the abnormalities that were examined on CBCT images. Overall preference for detecting the abnormalities irrespective of the imaging modality also showed no significant differences between SS and MD ($P \geq .2024$; Table II).

Figures 2A to 2C show the observers' preferences regarding the dental filter tool configurations based on the imaging modalities. On intraoral radiographs (Figure 2A), T-HDEF was significantly preferred for the detection of PLSW (66.7%, $P = .0481$), whereas B-LDEF was significantly preferred for the detection of G (100%, $P = .0125$) and F (100%, $P = .0125$). T-HDEF was also preferred for detecting IC (66.7%, $P = .0592$) and RF (66.7%, $P = .1250$); however, based on the number of abnormalities and binomial distribution analysis, no significant preference was observed. None of the observers preferred the combined filter for the detection of abnormalities on the intraoral radiographs. B-LDEF was significantly preferred for the detection of DD (75%, $P = .0130$), RF (75%, $P = .0337$) and ARC (75%, $P = .0337$) on panoramic radiographs (Figure 2B) and RF (81.8%, $P = .0014$) on the CBCT images (Figure 2C). The percentage of preferences for the combined filter was found to be low with all imaging modalities (≤25%), apart from the detection of F on

Table II. Overall observers' preference for diagnosing abnormalities with a standard screen and a medical display

Abnormality	*Standard screen preferred (%)*	*Equal preference (%)*	*Medical display preferred (%)*	*P value*
Periodontal ligament space widening	0	40	60	.2024
Incipient caries	5.6	46.0	48.4	.5722
Dens in dente	7.2	60.6	32.2	.9932
Granuloma	0	50	50	.8854
Fusion	0	83.4	16.7	.9844
Root fracture	13.9	50	36.1	.9608
External root resorption	16.7	50	33.4	.5360
Pulp stone	16.7	25	58.3	.6964
Additional root canal	11.1	55.6	33.4	.9270

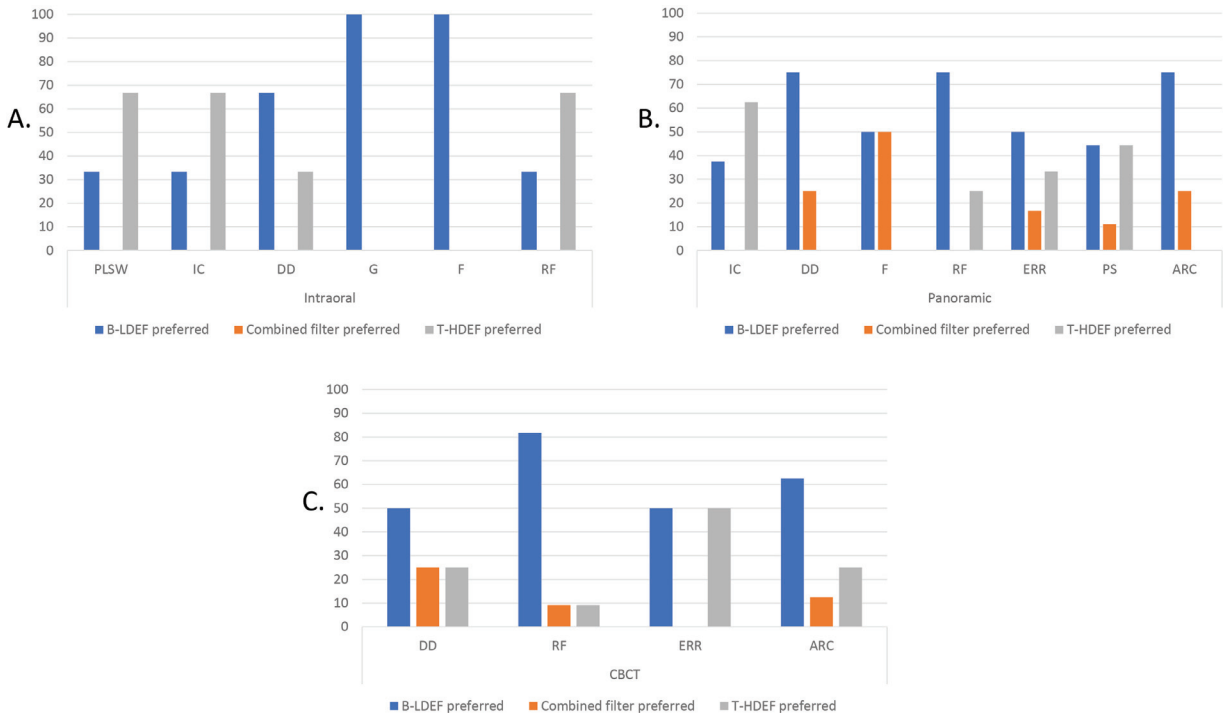


Fig. 2. Percentage of observers' preference for visualizing abnormalities with the 3 dental filter tool configurations: **(A)** intraoral radiographs, **(B)** panoramic radiographs, and **(C)** cone beam computed tomography. *B-LDEF*, bone−low density enhancement filter; *T-HDEF*, tooth−high density enhancement filter; *PLSW*, periodontal ligament space widening; *IC*, incipient caries; *DD*, dens in dente; *G*, granuloma; *F*, fusion; *RF*, root fracture; *ERR*, external root resorption; *PS*, pulp stone; *ARC*, additional root canals.

panoramic radiographs, which showed a 50% preference in favor of the combined filter.

Comparison of observers' overall preferences irrespective of the imaging modality for the dental filter tool configurations showed a significant preference in favor of B-LDEF for detecting DD (63.9%, $P = .0173$), G (100%, $P = .0001$), F (75%, $P = .0145$), RF (63.4%, $P = .0028$), and ARC (68.8%, $P = .0252$), whereas T-HDEF was significantly preferred by observers for detecting PLSW (66.7%, $P = .0114$) and IC (64.6%, $P = .0089$). No other significant findings were observed. Additionally, none of the filters was significantly preferred for the detection of ERR and PS ($P \geq .2179$; Table III). Figures 3A to 3H provide examples of raw radiographic images viewed with SS, MD, B-LDEF, T-HDEF, and a combined filter.

Overall, the intraobserver kappa values ranged between 0.75 and 0.90, representing good to excellent agreement, and the interobserver kappa values ranged between 0.63 and 0.72, indicating good agreement. No significant differences were detected between observers related to the visualization of subtle abnormalities with all screens. Observers were able to correctly diagnose all abnormalities with the 3 screens.

Table III. Overall observers' preference for diagnosing abnormalities with the 3 dental filter tool configurations

Abnormality	*B-LDEF (%)*	*Combined filter (%)*	*T-HDEF (%)*	*B-LDEF P value*	*Combined filter P value*	*T-HDEF P value*
Periodontal ligament space widening	33.3	0	66.7	.2849	.0624	.0114*
Incipient caries	35.4	0	64.6	.2866	.1289	.0089*
Dens in dente	63.9	16.7	19.4	.0173*	.1570	.1104
Granuloma	100	0	0	.0001*	.6297	.1866
Fusion	75	25	0	.0145*	.1518	.0609
Root fracture	63.4	3.0	33.6	.0028*	.2495	.0596
External root resorption	50	8.4	41.7	.2179	.5708	.5601
Pulp stone	44.4	11.1	44.4	.3289	.6243	.3289
Additional root canal	68.8	18.8	12.5	.0252*	.2399	.0571

B-LDEF, bone−low density enhancement filter; *T-HDEF*, tooth−high density enhancement filter.
*Statistically significant at $P < .05$.

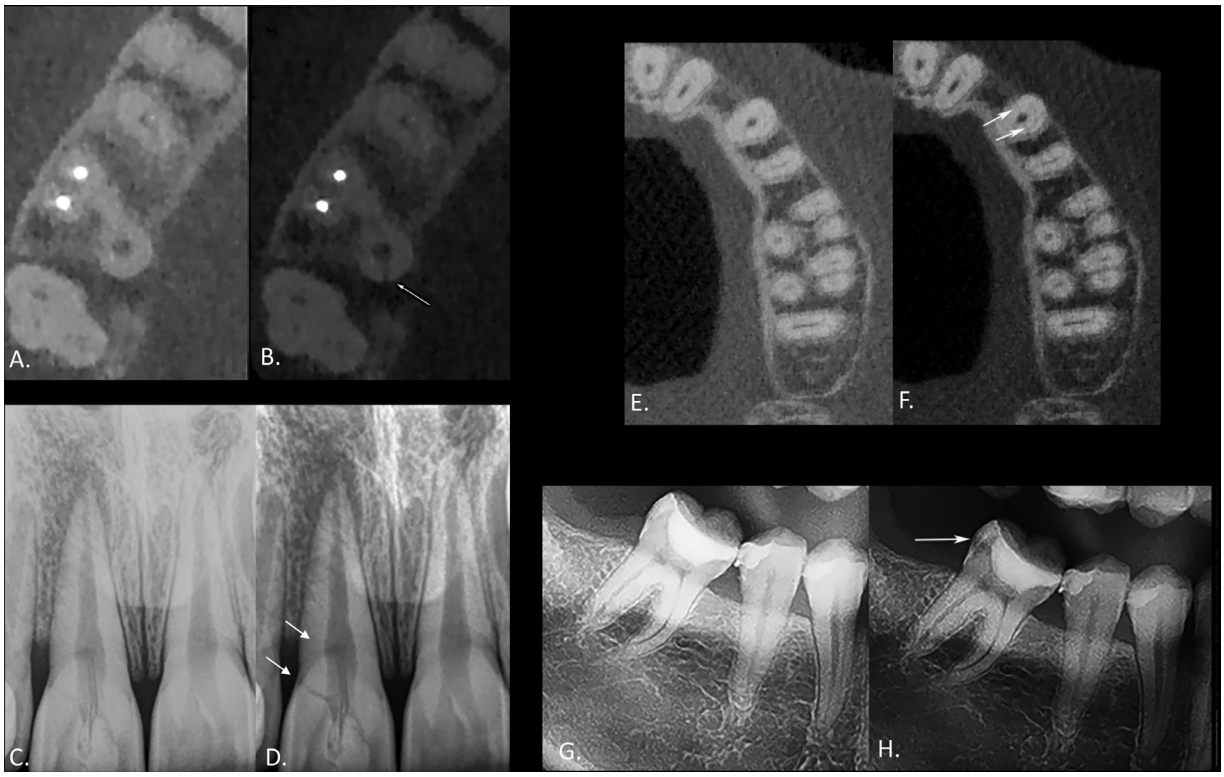


Fig. 3. Examples of abnormalities visualized with display monitors and filter tool configurations. **(A)** Maxillary right first molar root fracture not visualized on cone beam computed tomography (CBCT) axial view with standard screen. **(B)** Maxillary right first molar root fracture visualized on CBCT axial view with bone filter. **(C)** Maxillary right central incisor fracture lines difficult to visualize with combined filter. **(D)** Maxillary right central incisor fracture lines visualized with bone filter. **(E)** Maxillary left first premolar root fracture difficult to visualize on CBCT axial view with medical display. **(F)** Maxillary left first premolar root fracture visualized on CBCT axial view with bone filter. **(G)** Incipient caries on the distal surface of the right mandibular molar difficult to visualize on panoramic radiograph with standard screen. **(H)** Incipient caries on the distal surface of the right mandibular molar visualized on panoramic radiograph with tooth filter.

DISCUSSION

Both the null and alternative hypotheses were partially accepted, because no significant differences were observed between SS and MD for detecting the abnormalities, but MD with tooth and bone filters was significantly preferred over the combined filter (regular MD) by the observers for detection of most abnormalities.

In the digital imaging chain, performance of a display screen is of vital importance. For general dentists and endodontic specialists more specifically, the use of high-performance diagnostic displays and potential image enhancement tools are crucial to better assist the dentist in formulating diagnoses and treatment plans for patients. It has been shown that in dentistry, suboptimal monitor display may affect image quality, thereby leading to increased diagnostic errors.[4,21] However, mixed opinions have been documented whether medical-grade monitors offer superior observer preference.[22]

The results of our study showed an overall slightly greater preference in favor of MD but no significant differences were observed compared to SS. Although the SS and MD preferences were very different, with MD having greater preference, the large number of equal preferences made the preference for MD over SS nonsignificant. The term "equal preference" in this investigation was utilized to indicate no preference between either screen for the detection of each abnormality. These findings were inconsistent with other studies that found significantly higher preference for MD in identifying some anatomic structures and diseases.[13,14] Furthermore, the detection of specific abnormalities based on different imaging modalities showed no significant differences between the screens in the present study. On the other hand, Kallio-Pulkkinen et al.[13] showed a significantly higher preference in favor of MD for the detection of pathologic lesions. Unlike our findings, Baltacıoğlu et al. also reported a significant preference when using MD for detecting recurrent caries on CBCT scans.[18] These inconsistencies in the literature compared to our study could have resulted from the types of MD utilized, different study designs and imaging protocols, and variation in observer experience. However, they may have resulted mostly because of our samples, which included abnormalities that were subtle in nature.[23,24]

Based on the aforementioned findings, we utilized a dedicated dental filter tool incorporated into the MD to observe whether the different filter configurations could further enhance the observers' preference. With the exception of external root resorption and pulp stone, all other abnormalities showed a significant increase in observer preference with either B-LDEF or T-HDEF ($P \leq .0252$). No studies have assessed the preference of these configurations for the detection of dental anatomy or abnormalities. In the past, various image enhancement and filter tools have been proposed for improvement of diagnostic image quality.[25,26] Details of the implementation and functioning of these tools vary, and it is questionable which tool provides better improvement in image quality. Furthermore, a majority of the tools have either been incorporated into the imaging modality software or are available commercially, instead of being implemented directly into the display.[22] Medical displays currently on the market have been manufactured for medical diagnostic applications and the application of dentally calibrated monitors for clinical diagnostics in dentistry is not well established.[27]

Dental abnormalities require good diagnostic image quality for proper diagnosis. For instance, the difficulty of visualizing incomplete or complete root fracture may lead to misdiagnosis, hence directly influencing treatment planning.[28] For dental specialists, the effort to diagnose minute aberrations such as cracks or minor fracture lines is a daily challenge considering that they receive specific referrals of complex cases where the diagnosis is unclear. Furthermore, comprehensive information about root canal anatomy, the number of root canals, presence of accessory canals, and morphologic variations is essential for successful endodontic treatment. Therefore, a challenge exists for manufacturers to specialize the objective resolution of the MDs to fine-tune the viewing characteristics, allowing for optimized diagnostic image quality of dentomaxillofacial abnormalities. In the present study, a user-friendly dedicated dental filter tool was incorporated into the medical display to increase the visualization preference of observers. We believe that such integrated dedicated dental tools within the display may improve overall efficacy of radiodiagnostic systems, irrespective of their 2- or 3-dimensional nature. Therefore, from a general dental practice point of view, dentists might need a dual monitor-screen setup in a clinical practice, where one display with a dental filter tool could be completely dedicated for diagnostic purposes and another monitor for non-radiology-related tasks.

This study was focused toward introducing the concept of filters incorporated into the displays, which is lacking in the literature. Further studies are required comparing DICOM-compatible commercial off-the-shelf monitors and medical displays with dental configurations. In addition, future studies should concentrate on assessing multiple abnormalities instead of evaluating screen preference based on a single abnormality to deliver more clinically relevant information to clinicians.

One could argue that in the present investigation, more screens should have been used for comparison. In addition, all 4 observers who assessed the images in this study normally utilized an SS for diagnostic purposes in their clinical practice, which could have acted as a confounding factor and led to an unintentional habitual bias irrespective of the inherent properties of the display monitors. To keep this confounding factor to a minimum, the contours of the screens were hidden within a frame and images were pre-opened before being visualized by the observers. Further research should be conducted to observe whether dentists' habit of diagnosis utilizing a certain display can further influence their preference.

CONCLUSIONS

The study showed a slight increase in preference for MD over SS by observers for visualizing some difficult-to-diagnose dental abnormalities on intraoral and panoramic radiographs, but MD was not preferred over SS for detection of any abnormalities with CBCT. Overall, no significant differences were observed in preference for SS or MD ($P \geq .2024$). The use of MD combined with B-LDEF and T-HDEF configurations in a dental filter significantly enhanced observer preference for MD in the detection of most of the subtle abnormalities examined in this investigation ($P \leq .0252$). These dental filter configurations could in turn help improve standards of patient care.

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