PROXIMAL CARIES DETECTION ON SMARTPHONE DISPLAY

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A Thesis Submitted in Partial Fulfillment of the Requirements
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การตรวจฟันผุด้านประชิดบนหน้าจอสมาร์ตโฟน

น.ส.นภัส ลักนะก่อเกียรติ

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต

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Thesis Title	PROXIMAL CARIES DETECTION ON SMARTPHONE DISPLAY
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การศึกษานี้มีวัตถุประสงค์เพื่อเปรียบเทียบความแม่นในการตรวจหาฟันผุด้านประชิดระหว่างภาพรังสีกัดปีกที่ส่งออกจากซอฟต์แวร์ระบบการสื่อสารและการเก็บภาพถาวร กับภาพที่ถ่ายด้วยสมาร์ตโฟน โดยดูผ่านหน้าจอสมาร์ตโฟน ด้านประชิดจำนวนทั้งหมด 200 ด้านในภาพรังสีกัดปีกดิจิทัลถูกเลือกให้เข้าร่วมการศึกษานี้ ภาพของภาพรังสีทั้งหมดได้รับการถ่ายจากหน้าจอเกรดการแพทย์และหน้าจอทั่วไปโดยใช้ไอโฟนแปดพลัส และเก็บให้อยู่ในรูปแบบของแฟ้มข้อมูลเจเพ็ก แฟ้มข้อมูลภาพถ่ายดิจิทัลและการสื่อสารในการแพทย์ที่ถูกส่งออกได้รับการเปลี่ยนให้อยู่ในรูปแบบของแฟ้มข้อมูลเจเพ็กและถ่ายโอนมายังสมาร์ตโฟนเครื่องที่ใช้ในการถ่ายภาพ ด้านประชิดแต่ละด้านได้รับการให้คะแนนจากผู้สังเกตจำนวน 7 ท่านด้วยมาตรวัดห้าระดับ สถิติแคปปาถ่วงน้ำหนักถูกนำมาใช้เพื่อหาค่าความสอดคล้องภายในตัวและระหว่างผู้สังเกต รังสีแพทย์ช่องปากที่ได้รับการรับรองจำนวน 3 ท่านประเมินภาพชุดเดียวกันบนหน้าจอเกรดการแพทย์ ความเห็นพ้องที่ได้ถูกนำมาคำนวนหาสภาพไวสภาพจำเพาะ ความแม่น ค่าทำนายผลบวก ค่าทำนายผลลบ และสร้างเป็นกราฟเส้นโค้งอาร์โอซี การทดสอบค่าทีและการวิเคราะห์ความแปรปรวนทางเดียวถูกใช้เพื่อเปรียบเทียบค่าเฉลี่ยของพื้นที่ใต้เส้นโค้ง ระหว่างฟันผุระดับเนื้อฟันและเคลือบฟันและระหว่างวิธีการได้ภาพทั้งสามวิธี

ผลการศึกษาพบว่า ค่าความสอดคล้องภายในตัวและระหว่างผู้สังเกตอยู่ในช่วงระหว่าง "ความสอดคล้องปานกลาง" ถึง "ความสอดคล้องดีมาก" การเปรียบเทียบค่าเฉลี่ยของพื้นที่ใต้เส้นโค้งแสดงให้เห็นค่าที่สูงกว่าอย่างมีนัยสำคัญในกลุ่มของภาพที่ถูกส่งออก ในขณะที่ไม่พบความแตกต่างอย่างมีนัยสำคัญระหว่างกลุ่มของภาพที่ได้รับการถ่ายจากหน้าจอเกรดการแพทย์และกลุ่มของภาพที่ได้รับการถ่ายจากหน้าจอทั่วไป พบความแตกต่างอย่างมีนัยสำคัญระหว่างค่าเฉลี่ยของพื้นที่ใต้เส้นโค้งในการตรวจหาฟันผุระดับเนื้อฟันในกลุ่มภาพทุกกลุ่ม สำหรับฟันผุระดับเคลือบฟัน เฉพาะค่าเฉลี่ยของพื้นที่ใต้เส้นโค้งในกลุ่มของภาพที่ถูกส่งออกเท่านั้นที่มีค่าสูงกว่าอย่างมีนัยสำคัญ

การตรวจหาฟันผุด้านประชิดควรกระทำโดยใช้ภาพที่ถูกส่งออกโดยตรงจากซอฟต์แวร์ระบบการสื่อสารและการเก็บภาพถาวร ภาพที่ได้รับการถ่ายควรใช้ในการประเมินด้วยความระมัดระวัง เนื่องจากมีปัจจัยจำนวนมากที่สามารถส่งผลถึงคุณภาพของภาพได้

สาขาวิชา	รังสีวิทยาช่องปากและแม็กซิลโลเฟเชียล	ลายมือชื่อนิสิต ....
ปีการศึกษา	2562	ลายมือชื่อ อ.ที่ปรึกษาหลัก ....

6175823332 : MAJOR ORAL AND MAXILLOFACIAL RADIOLOGY
KEYWORD: digital radiograph, display, proximal caries, smartphone

Napas Lappanakokiat : PROXIMAL CARIES DETECTION ON SMARTPHONE DISPLAY. Advisor: Assoc. Prof. SOONTRA PANMEKIATE, Ph.D.

The aim of this study was to compare diagnostic accuracy in proximal caries detection between bitewing radiographs exported from PACS software and taken with a smartphone viewed in a smartphone display. A total of 200 proximal surfaces from digital bitewing radiographs were included in this study. Images of all radiographs were captured from a medical-grade and a common display by an iPhone 8 Plus and stored as JPEG files. Exported DICOM files were converted into JPEG format and transferred to the smartphone used for image capturing. Each proximal surface was rated by 7 observers with 5-point-scale. Weighted kappa test was used to determine intra- and inter-observer agreements. Three certified oral radiologists evaluated the same images on the medical-grade display. Obtained consensus was used to calculate sensitivity, specificity, accuracy, positive predictive value, negative predictive value and generate ROC curves. T-test and one-way ANOVA were used to compare mean AUC between dentinal and enamel caries and among three image acquiring methods.

The result showed that inter- and intra-observer agreement ranged from “moderate” to “almost perfect”. Comparison of mean AUC showed significant higher value in group of exported images. While there was no significant difference between group of images captured from a medical-grade display and images captured from a common display. Significant differences between mean AUC in detection of dentinal caries were seen in all image groups. For enamel caries, only mean AUC in group of exported images was significantly higher.

Detection of proximal caries should be done using directly exported images from PACS software. Captured images should be evaluated with caution since considerable factors can affect image quality.

Field of Study:	Oral and Maxillofacial Radiology	Student's Signature ....
Academic Year:	2019	Advisor's Signature ....

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Last but not least, I extend my gratitude to all inspirational music in the world that keeps me uplifted and concentrated.

Love myself, love yourself.

Peace.

Napas Lappanakokiat

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Background and Rationale

Digital radiography gradually becomes common in today dental practice. The advantages, comparing to conventional technique, include easier processing, time saving, cost reduction in long term and environmental friendliness. Moreover, the images can be stored for a very long time without quality changes and can be transmitted electronically.

One of the most important parts in digital radiographic system is the display. As a final device that shows resultant images, an underqualified display can compromise the image quality and lead to misinterpretation and misdiagnosis. Also, well-calibrated monitors reduce eye strain and fatigue (1). Medical-grade displays are invented as assisting tools in medical radiograph assessment. These monitors can be adjusted to comply with a certain protocol, called the Digital Imaging and Communication in Medicine (DICOM) Part 14 Greyscale Standard Display Function standard (GSDF) (2). This named guideline is developed by experts in the American Association of Physicists in Medicine (AAPM) and the National Electrical Manufacturers Association (NEMA). However, this type of display is very expensive and may be unaffordable in community hospitals or small clinical settings. Therefore, cheaper off-the-shelf PC monitors are alternately used. Tablet devices and smartphones are also selected, especially in case consulting, as they are portable, easy-to-use and more budget friendly.

A smartphone is a portable device that can perform many functions of a computer, usually having a touchscreen interface, internet access, and an operating system capable of running downloaded applications. Nowadays, smartphone usage is near-universal. Many healthcare providers use their smartphones to transmit patient-related information, including taking pictures of medical records or radiographs and sending them to one another via instant messaging application (3).

Bitewing radiographs are the essential diagnostic tool in proximal caries diagnosis, especially non-cavitated lesions. Commonly, radiolucency cannot be detected in a radiograph unless the affected areas are more than 30 – 40% demineralized (4). As the true depths of proximal caries are always greater than those observed, it is suggested that this type of lesion be found as early as possible (5). Still, this can be challenging because of indistinct radiolucency in incipient caries. Consequently, monitors with adequate quality should be used to show such precise details. The effectiveness among displays available in today's market, especially smartphones' displays, is not yet thoroughly studied and the results remain controversial (6-12).

The aim of this study is to compare diagnostic accuracy in proximal caries detection between bitewing radiographs exported from PACS software and taken with a smartphone viewed in a smartphone display.

Review of Literature

Prevalence of dental caries in Thailand

According to Thailand 8th National Oral Health Survey conducted in 2017, a prevalence of dental caries in permanent teeth of 12-year-old children is 52.0%, which was slightly decreased from the last survey (52.3%) performed in 2012 (13).

A study that aimed to investigate the prevalence of proximal caries from posterior bitewing radiographs in children with no visible cavitated lesions, recruited 133 eleventh grade students in Supanburi Province. It was found that 64 students (48.12%) of the recruited students had proximal caries (14). This figure is similar to a result from another study conducted in Department of Hospital Dentistry, Mahidol University, Bangkok, which sampled 76 patients who attended the department and were exposed to bitewing radiography. The authors reported a prevalence of 47.37% for proximal caries in adults with an average age of 29 years old (15).

Demirci et al. (16) investigated 11,915 carious surfaces in 2,383 teeth in which 281 central incisors, 291 lateral incisors, 181 canines, 269 first premolars, 290 second premolars, 536 first molars and 535 second molars were included. It can be concluded from their data that out of 3,260 proximal surfaces from the sampled posterior teeth, 823 surfaces were affected by caries. The prevalence could be calculated as approximately 25.25%.

Another study (17) sampled 951 17- and 23-year-old males and females who participated in a clinical epidemiological survey conducted in four midsize or large Dutch communities in 1993. A total of 12,233 proximal surfaces were examined. The authors found that 1,372 surfaces had carious lesions that extended into dentine, while the rest (10,861 surfaces) were sound or had only enamel lesions. The prevalence of dentinal caries was calculated to be 11.2%.

Thresholds in restorative treatment for proximal caries

Typical appearance of proximal caries usually seen in dental radiographs is a triangular-shaped, radiolucent area with broad base at the tooth surface spreading along the enamel rods. However, other appearances such as a notch, a dot, a band, or one or more thin lines can be detected. When the demineralization reaches the dentino-enamel junction (DEJ), it spreads along the junction, forming the base of the second triangle with apex directed toward the pulp chamber. The most susceptible area for proximal caries is the area between the contact point and the free gingival margin. Proximal caries never starts below the gingival margin (4).

Restorative treatment threshold varied substantially among dentists. A study conducted by Gordan et al. (18) aimed to quantify at which proximal caries lesion depths dentists in regular clinical practice intervene restoratively and identify the characteristics that were associated with restorative intervention. They found that the decision depended on various factors, such as caries risk of a patient, practice busyness, type of practice model and gender. Proximal caries detected in patients with high caries risk were more likely to be restored even if they were still limited in enamel portion. Enamel lesions detected in less busy workplace were prone to be recommended for restoration. Dentists working in large-group private practice and public health practice were less likely to restore enamel lesions, as compared to practitioners who worked in solo or small group private practice. In addition, male dentists tended to intervene the spotted lesions more than female dentists.

A systematic review and meta-analysis performed by Innes and Schwendicke (19) showed that dentists were 1.98 times more likely to restore proximal lesions confined to enamel in high caries risk groups, as compared to low caries risk groups. The authors also did not find any significant trend of this proportion changing with time, as the percentages of dentists or dental therapists in pooled publication 15 and 10 years ago who stated that they would intervene enamel lesion are 24% and 27%, respectively.

Therefore, radiographic diagnosis alone is not enough to determine whether the detected carious lesions should be intervened restoratively.

Standards used to determine the presence of carious lesions

There are many "gold standard" suggested by researchers to determine whether the studied teeth have existing carious lesions. One of the most used method is serial sectioning of a tooth with a low-speed saw and a diamond blade. These thin sections will then be examined microscopically to evaluate a presence of caries, which can be observed as opaque white to dark brown color changes in an area at risk of caries on the proximal surfaces. An opinion of a specialist in oral pathology or a consensus between a specialist and the researchers' team are used as a reference for further statistical analysis (10-12). Micro-computed tomography (micro-CT) machine can also be used to display the demineralized areas as well as their depths. Carious lesions can be considered if there is a radiolucent area that is darker than the surrounding enamel or dentine (7). Another method is using biochemical concentration assays to quantify the transfer of calcium and phosphate from the enamel surface to the buffering solution. Demineralization can be confirmed when there is an increase of concentration in post-buffer solution comparing to pre-buffer solution (6).

However, *in vivo* studies cannot use the above methods as a reference since in that settings, the examiners cannot retrieve studied samples from the living patients to evaluate histologically or biochemically. Instead, opinions from senior staffs or a consensus from two or more specialists are considered an acceptable "silver standard". Evaluation of chest radiographs (3), four knee trauma series radiographs with two axial CT scan sections (20) and radiographs of upper extremities, lower extremities, pelvis and spine (21) were evaluated and the data was statistically analyzed with the "silver standard" as a reference.

In the field of dentistry, an *in vivo* study conducted by Mepparambath et al. (22) which aimed to compare the accuracy between laser fluorescence and bitewing radiography at detecting proximal caries in primary teeth, also used the interpretation of bitewing radiographs by specialists in pedodontics and preventive dentistry as a criteria. Another *in vivo* study (23) with an objective to assess the diagnostic property of intraoral bitewing radiographs and periapical radiographs in proximal caries detection at different level of caries progression also used an agreement among eight experienced faculty members from Harvard School of Dental Medicine with 27 and 35 years of experience as a consensus reference.

Diagnostic accuracy comparison between medical grade displays and other common displays

Hellén-Halme et al. (11) investigated the accuracy of proximal caries detection in digital radiograph by comparing one common display monitor with two medical grade display monitor. There is no statistical difference between types of monitor on accuracy of proximal caries detection. In addition, Isidor et al. (12) reported that one of the two non-medical grade displays showed higher sensitivity in proximal caries detection on digital radiograph than medical grade display, but the relation between the accuracy of proximal caries detection, screen resolution and price of display monitor are still unclear. Moreover, Vasconcelos et al. (9) investigated the effectiveness of various types of display monitor on the detection of vertical root fractures by comparing one common monitor, one notebook display and two tablet displays. There is no statistical difference in vertical root fracture detection among types of display monitor. Also, Tadinada et al. (8) reported no statistical difference between common monitors and tablet displays on depicting maxillofacial radiographic landmarks.

In contrast, Araki et al. (7) investigated the effect of display monitor devices on digital radiographic caries diagnosis by comparing between one common monitor, one medical-grade monitor and one tablet display. The result showed the tablet display had lower diagnostic accuracy than the common monitor and the medical-grade monitor especially for superficial caries, but there is no significant difference between the common monitor and the medical-grade monitor on diagnostic accuracy of superficial caries. Whereas, Countryman et al. (6) compared the performance of 5 different displays (one common monitor, two medical-grade monitors and two tablet displays) in the detection of artificial incipient and recurrent caries-like lesions. The result showed no significant difference among the 3 types of display monitors. However, the auto-calibrating medical-grade monitors performed better when incipient and recurrent lesions were compared.

Image acquiring methods

There are several studies that consider a smartphone as an image-capturing tool to quickly digitalize displayed radiographs and store the images in the device with no need to export them from the database. Giordano et al. (20) took pictures of four knee trauma series radiographs (AP, lateral, and forty-five degree oblique views) and two axial CT scan sections using an iPhone 5 at a distance of 20 centimeters. Stahl et al. (24) captured entire CT scans of thoracic and lumbar spines in axial, sagittal, and coronal plane by an iPhone 6 video camera. Moreover, in a study of Handelman et al. (3), a specialized housing was constructed to standardize image acquiring process. It was used to hold a Samsung Galaxy S6 at a fixed distance of 30 centimeters from a monitor, flat angle and central elevation.

Every still image in mentioned study were recorded as JPEG format since DICOM files are not compatible in many devices without DICOM reader software, including smartphones. Chandhanayingyong et al. (21) also used JPEG format in their study about accuracy and usefulness of teleconsultation in emergency orthopedic patients.

Sample size estimation for diagnostic test analysis

Sensitivity and specificity analysis is commonly used for screening and diagnostic tests. If an objective of the research study is to determine whether a specific tool or instrument can be used as a screening tool, then researchers will have to ensure that it has a sufficiently high degree of sensitivity but a lower degree of specificity can be tolerated. On the other hand, if researchers plan to develop a specific tool or instrument to be used as a diagnostic tool, a high degree of both sensitivity and specificity will usually be targeted. There is a study that provided sample sizes tables with regards to sensitivity and specificity analysis. The tables recommended the minimum sample sizes required for obtaining the desired sensitivity, specificity, power and type I error for a range of low to high prevalence of the disease (25).

However, using digital bitewing radiographs for proximal caries detection has quite wide range of sensitivity (53 - 93 %) and specificity (67 - 93 %) (26-29). The obtained results may be affected by characteristics and variation of cases included in each study. Caries that have already penetrate into dentine are easier to detect, so high proportion of dentinal caries in the selected samples may contribute to high sensitivity and specificity of the obtained results. While in studies that focused on enamel proximal caries, the detection is much more challenging and lower sensitivity may be acquired. There are studies that most of the selected samples consist of enamel lesions and only 14 - 17% of sensitivity are reported (12, 30).

Moreover, there is a study (23) that compared the diagnostic property between intraoral bitewing radiographs and periapical radiographs for early stage proximal caries. Fourteen periapical radiographs and four bitewing radiographs stored in the electronic health record system were randomly exported without any personal identifiers. The observers examined the proximal surfaces of bitewing images and graded them as either “intact”, “enamel caries < 1/2 width”, “enamel caries > 1/2 width”, or “caries into dentine”. The selected periapical images were examined 2 weeks later in the same manner. The authors found no significant differences between the two techniques but there was significant difference in sensitivity when detecting dentinal caries and enamel caries that only confined in the outer half of enamel thickness. Hence, it is difficult to determine the expected sensitivity and specificity in both null and alternative hypothesis when using medical-grade display and smartphone display as an adjunctive tool in proximal caries diagnosis.

A study of Hintze et al. (31), aiming to evaluate the influence of the number of surfaces and the number of observers on the statistical power of a study comparing the diagnostic accuracies of radiographic systems used for proximal caries lesion detection, radiographed 338 interproximal surfaces from 177 extracted human teeth by 4 different radiographic systems including both conventional and digital technique. The images were assigned to 10 observers to evaluate the presence of carious lesions. Then, receiver operating characteristic (ROC) curves of each system used by each observer, 40 curves in total, were plotted and the correlation between the different ROC curve areas (A_zs) were analyzed by a two-way analysis of variance (two-way ANOVA). They found that number of surfaces and the number of observers had only marginal influence on the statistical power. The study designs for comparing the accuracy of several systems can be composed freely in relation of number of surfaces and observers as long as the total number of evaluations per system are identical.

However, the specialty and experience of each observer may affect the diagnostic outcome when it comes in term of proximal caries detection. Another study (32) used kappa statistics to evaluate inter-rater agreement of 34 dentists in determining the presence or absence of caries and the depth of caries in bitewing radiographs. The observers consisted of 13 general practitioners, 8 dentists specialized in operative dentistry and 13 dentists from the department of Dental Diagnostic Science. The authors found that among those three groups, kappa value obtained from observers whose expertise was diagnostic dentistry was the highest. When compared to the other two groups, the differences were also statistically significant. The result was due to the fact that dentists working in the department of Dental Diagnostic Science have received more radiology training than the others. The authors also suggested that in situations when several opinions are required to reach a consensus without previous calibration between observers as occurs in everyday practice, dentists with radiology training are more consistent in their diagnoses.

Research Question, Hypothesis and Research Objective

Research question

Is diagnostic accuracy in proximal caries detection affected by different image acquiring methods?

Hypothesis

Exported digital bitewing radiographs viewed in a smartphone can provide the same accuracy in proximal caries detection as images that are smartphone-captured from a medical-grade display and a common display.

H_0: $\mu_1 = \mu_2 = \mu_3$

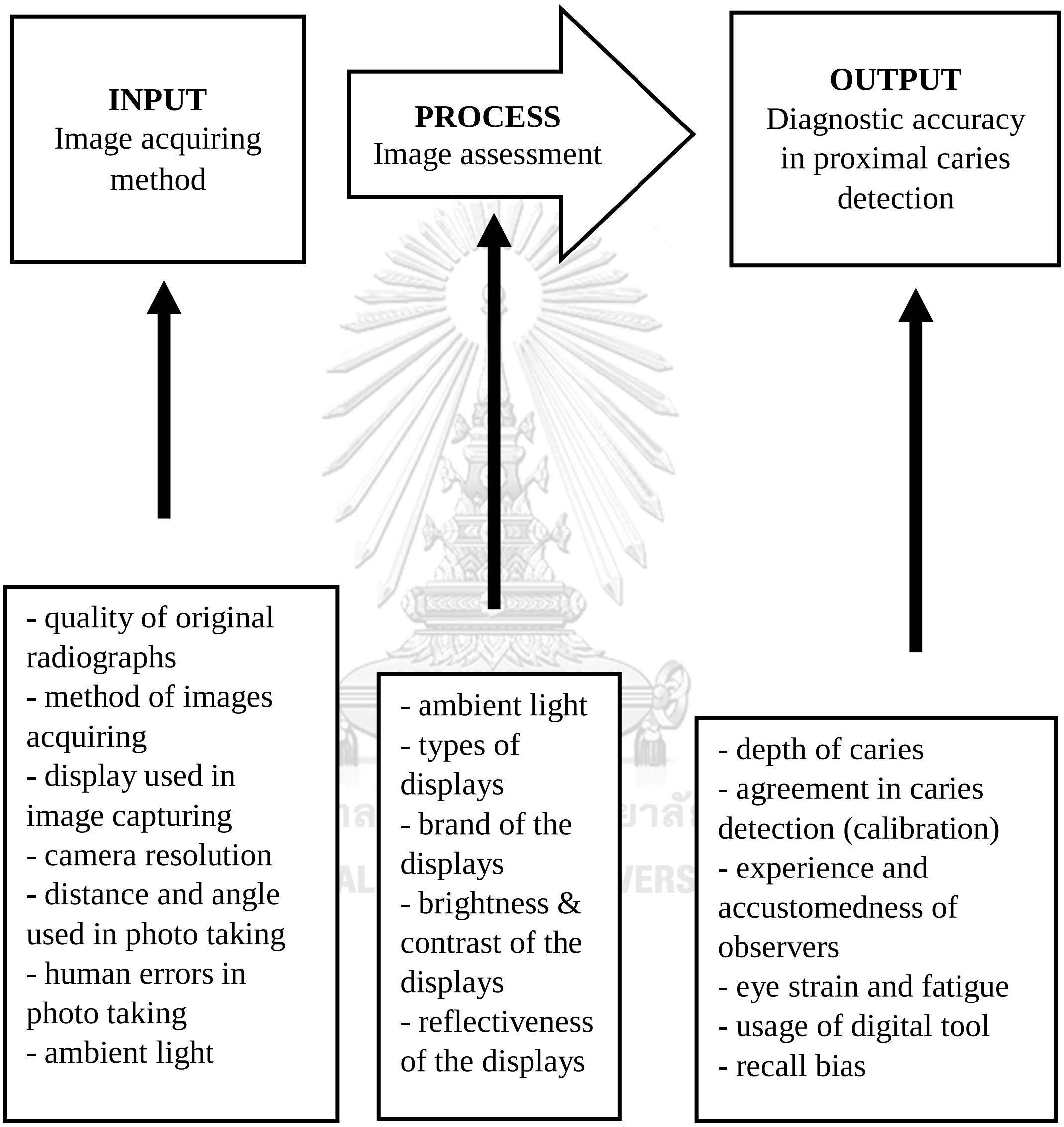
H_a: $\mu_1 \neq \mu_2 \neq \mu_3$

(when 1 is exported digital bitewing radiographs, 2 is smartphone-captured images from a medical-grade display and 3 is smartphone-captured images from a common display)

Research objective

To compare diagnostic accuracy in proximal caries detection between bitewing radiographs exported from PACS software and smartphone-captured images viewed in a smartphone display

Conceptual Framework



Research Methodology

Samples

A total of 200 proximal surfaces from digital bitewing radiographs stored in Chulalongkorn University Dental Hospital's Picture Archiving and Communication System (PACS) software were consecutively selected. The number of sampled surfaces was mentioned in previous studies (10, 11). Distribution of enamel and dentinal lesion was determined from another study (17), resulting in 24 dentinal caries and 176 surfaces which were either sound or had carious lesions confined within enamel. Proximal surfaces, starting from mesial surfaces of first premolars to mesial surfaces of third molars (if present) of each quadrant, were observed. Inclusion and exclusion criterion were as following;

Inclusion criteria

- Acceptable quality: No overexposure or underexposure, no cone cutting and artifacts
- No overlapping between each proximal surface

Exclusion criteria

- Surfaces with proximal restorations, fixed prostheses or orthodontic appliances
- Surfaces that are approximated to edentulous areas or retained roots

Image acquiring methods

Images of all selected radiographs were captured as JPEG files with an iPhone 8 Plus (Apple, Cupertino, CA, USA) using its 12-megapixel camera by the author. A “Mono” filter, which fully desaturates a captured image with no adjustment to brightness and contrast, was selected. Specialized housing was used to stabilize the phone during image capturing (Figure 1). The housing was placed 42.5 centimeters (17 inches) away from a medical-grade display (Barco MDCC-6430, Barco NV, Kortrijk, Belgium) and 50 centimeters (20 inches) away from a common display (HP ProOne 600 G3, HP Inc., CA, USA) in flat angle and central elevation to reduce moiré pattern on the captured images. The ambient light intensity during image capturing process for both displays was controlled and confirmed by a densitometer (Uni-T UT383, Uni-Trend Group Limited, Kowloon, Hong Kong) to be at approximately 360 lux (Figure 2 - 5). Before image capturing, all images on both displays were set to be at the center of the phone’s screen and the area was lightly tapped once to ensure the images’ focus point. Exported DICOM files without any patient-related data were also converted into JPEG format and transferred to the same smartphone used for image capturing. The specification of all displays are shown in Table 1.

Selected digital radiographs were evaluated via the medical-grade display (Barco MDCC-6430, Barco NV, Kortrijk, Belgium) for the presence of proximal caries by 3 oral and maxillofacial radiologists. All were certified with diploma of the Thai board of oral diagnostic sciences. They rated each surface as either “sound”, “caries at outer ½ of enamel”, “caries at inner ½ of enamel” or “caries into dentine” which were similar to the previous study (23). Each radiologist examined all sampled surfaces independently. If there were discrepancies in the results, they discussed together to reach an agreement. Their consensus was used as the standard. The data collection forms for radiologists are shown in Table 2 and 3.

Table 1 shows specification of each display.

Type of monitor	**iPhone 8 Plus Smartphone screen**	**HP ProOne 600 G3 Desktop PC**	**Barco MDCC-6430 Medical-grade screen**
Type of display	Color LCD monitor with IPS technology	Color LCD monitor with IPS technology	Color LCD monitor with IPS technology
Display size	5.5”	21.5”	30”
Resolution (pixels)	1920 x 1080	1920 x 1080	3280 x 2048
Contrast ratio	1,300:1	1,000:1	1,500:1
Maximum Luminance	625 cd/m²	250 cd/m²	1,050 cd/m²

(a) (b) (c)

Figure 1 shows a housing used to stabilize the smartphone during image capturing. ((a) back side of the housing, (b) front side of the housing, (c) lateral side of the housing)

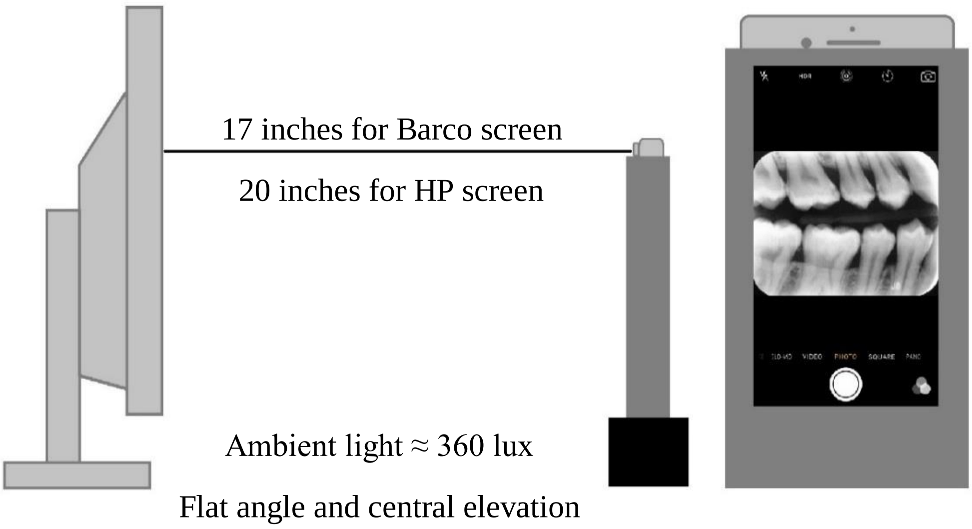


Figure 2 shows a simulation of device setting and smartphone screen shown during image capturing. Two different distances are used for each display due to difference in screen size.

Figure 3 shows frontal view of device setting and smartphone screen shown during image capturing from a medical-grade display.

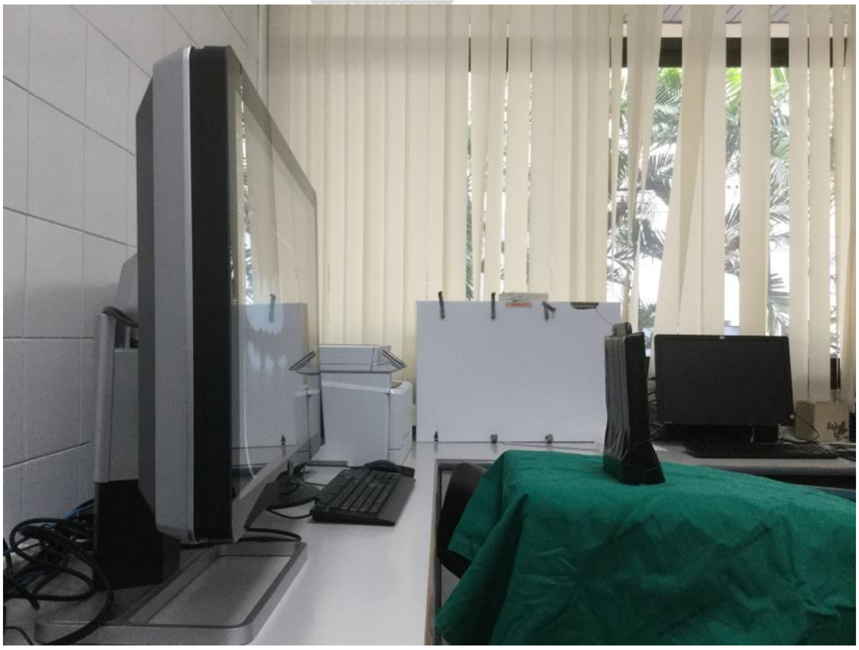
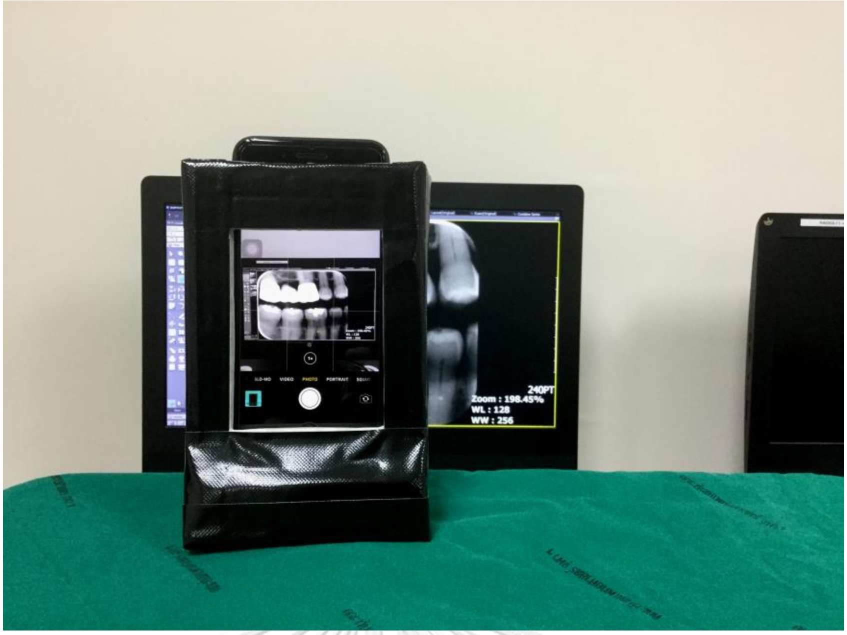
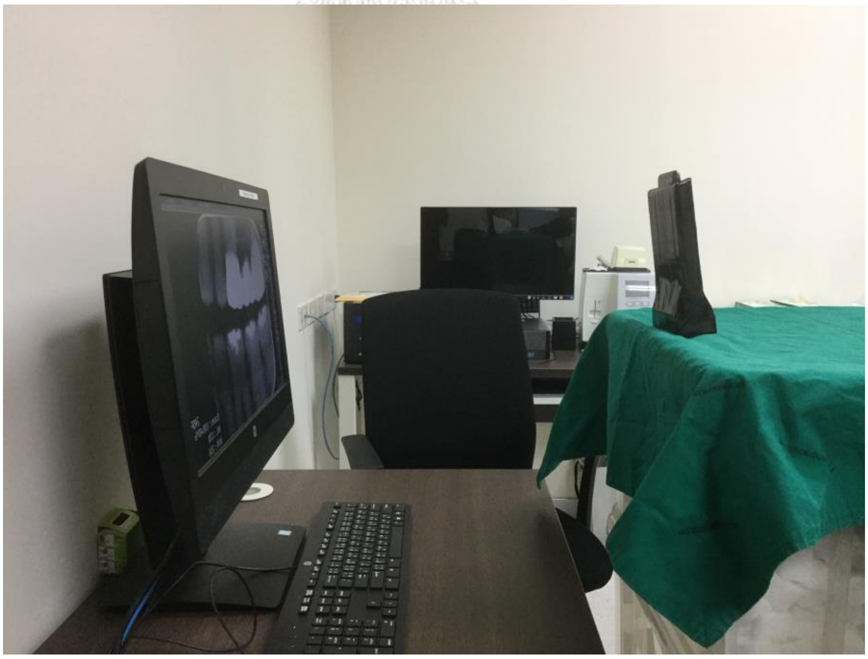


Figure 4 shows lateral view of device setting during image capturing from a medical-grade display.



<u>Figure 5</u> shows frontal view of device setting and smartphone screen shown during image capturing from a <u>common display</u>.



<u>Figure 6</u> shows lateral view of device setting during image capturing from a <u>common display</u>.

Table 2 shows an example of data collection form for 3 certified radiologists, in a case that all proximal surfaces comply with the inclusion criteria.

Image No. 1																		
Surface / Caries	14	14	15	15	16	16	17	17	18	44	44	45	45	46	46	47	47	48
	M	D	M	D	M	D	M	D	M	M	D	M	D	M	D	M	D	M
1																		
2																		
3																		
4																		

(1 = sound, 2 = caries at outer ½ of enamel,

3 = caries at inner ½ of enamel and 4 = caries into dentine)

Table 3 shows an example of data collection form for 3 certified radiologists, in a case that not all proximal surfaces comply with the inclusion criteria.

Image No. 1																		
Surface / Caries	14	14	15	15	16	16	17	17	18	44	44	45	45	46	46	47	47	48
	M	D	M	D	M	D	M	D	M	M	D	M	D	M	D	M	D	M
1																		
2																		
3																		
4																		

(1 = sound, 2 = caries at outer ½ of enamel,

3 = caries at inner ½ of enamel and 4 = caries into dentine)

Observers and image evaluation

Obtained images were categorized as following;

1. DICOM Images directly exported from PACS software and converted into JPEG format
2. Smartphone-captured images from a medical-grade display in JPEG format
3. Smartphone-captured images from a common display in JPEG format

An example of three sampled digital bitewing radiographs, obtained from three different image acquiring methods are shown in Figure 6. All three groups of images with randomly arranged order were assessed by 7 observers in one occasion. The observers consisted of 3 oral and maxillofacial radiologists with 10, 20 and 43 years of experience, 2 in operative dentistry with 6 and 7 years of experience and 2 general practitioners with 10 years of experience. The number of observers was determined according to previous studies (10, 11). Each observer was assigned to evaluate the images independently in a room with ambient light <100 lux. Brightness, contrast and magnification could be subjectively adjusted. Each proximal surface of selected tooth was rated by 5-point-scale (1 = caries definitely absent, 2 = caries probably absent, 3 = unsure if caries absent or present, 4 = caries probably present and 5 = caries definitely present). Intra-observer agreement was tested after 30 days, by re-assessing 30% of the sample (60 surfaces). The data collection forms for observers are shown in Table 4 and 5. The flow chart showing steps of research method is presented in Figure 7.

(a)

(b)

(c)

Figure 6 shows three images of sampled digital bitewing radiograph from three different image acquiring methods. ((a) image directly exported from PACS software, (b) image captured from a medical-grade display, (c) image captured from a common display)

Table 4 shows an example of data collection form for 7 observers,

in a case that all proximal surfaces comply with the inclusion criteria.

Image No. 1																		
Surface / Caries	14 M	14 D	15 M	15 D	16 M	16 D	17 M	17 D	18 M	44 M	44 D	45 M	45 D	46 M	46 D	47 M	47 D	48 M
1																		
2																		
3																		
4																		
5																		

(1 = caries definitely absent, 2 = caries probably absent, 3 = unsure if caries absent or present, 4 = caries probably present and 5 = caries definitely present)

Table 5 shows an example of data collection form for 7 observers,

in a case that not all proximal surfaces comply with the inclusion criteria.

Image No. 1																		
Surface / Caries	14 M	14 D	15 M	15 D	16 M	16 D	17 M	17 D	18 M	44 M	44 D	45 M	45 D	46 M	46 D	47 M	47 D	48 M
1																		
2																		
3																		
4																		
5																		

(1 = caries definitely absent, 2 = caries probably absent, 3 = unsure if caries absent or present, 4 = caries probably present and 5 = caries definitely present)

Statistical analysis

All statistical analyses were performed in SPSS Software version 22. Weighted kappa test was used to determine intra- and inter-observer agreements. Obtained data from each observer was used to generate the receiver operating characteristic (ROC) curves. T-test and Analysis of variance (ANOVA) were used to compare the mean area under the curves (AUC) between enamel and dentinal caries and among the three image acquiring methods, respectively. The significance level was set at 0.05.

Ethical consideration

Since radiographs stored in PACS system contain patient's data, Ethical approval was obtained from the Human research ethics committee (Faculty of Dentistry, Chulalongkorn University) prior to the experiment (HREC-DCU 2020-015).

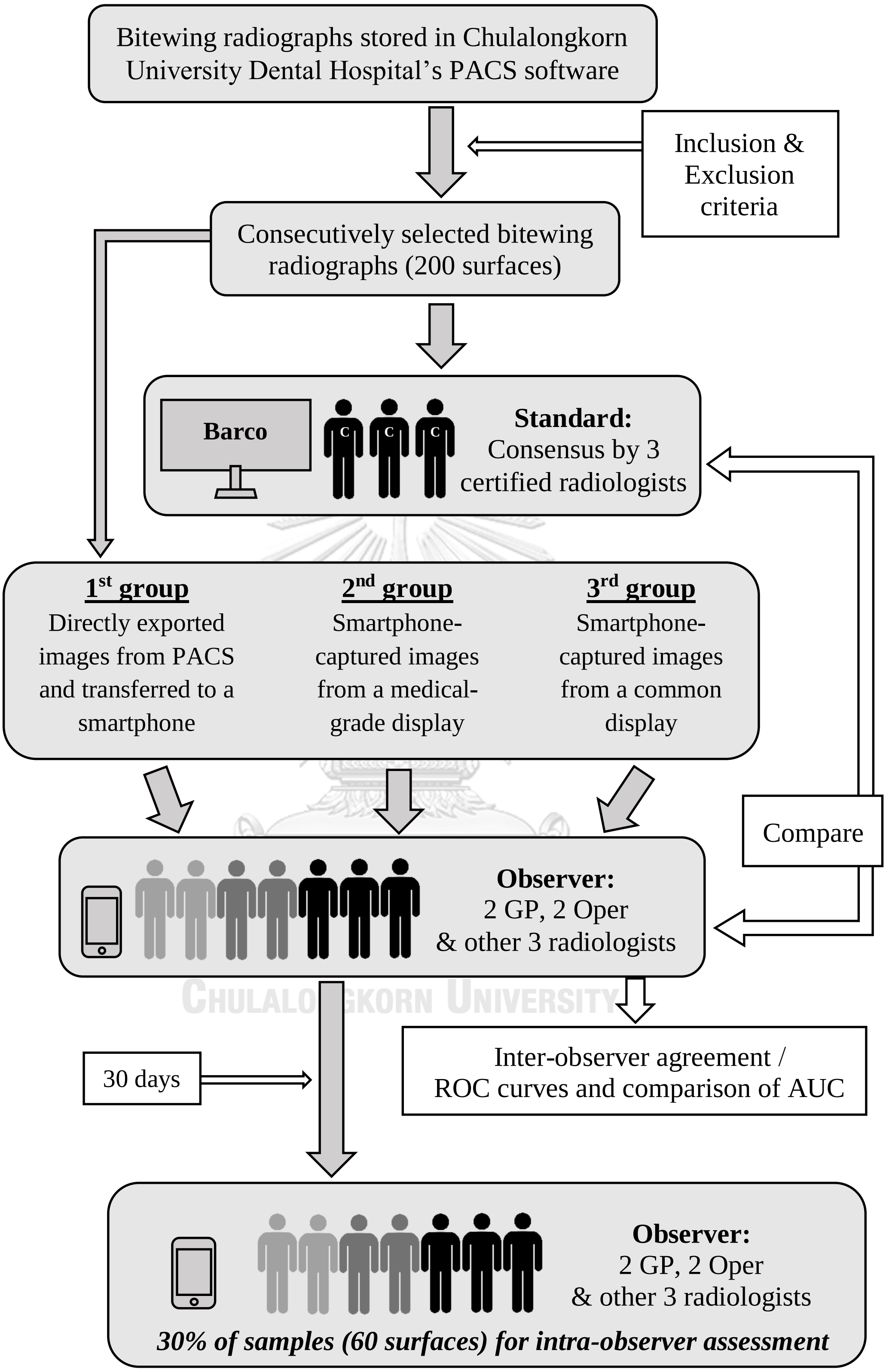


Figure 7 shows steps of research methodology as a flow chart.

Results

Twenty-seven digital bitewing images, taken in February of 2020, were included in this study. A total of 200 proximal surfaces were evaluated by 3 certified oral and maxillofacial radiologists using a medical-grade display (Barco MDCC-6430, Barco NV, Kortrijk, Belgium). Their consensus reported 24 surfaces (12%) with dentinal caries, 29 surfaces (14.5%) with caries limited to inner ½ of enamel, 31 surfaces (15.5%) with caries at outer ½ of enamel and 116 sound surfaces (58%) (Table 6).

Table 6 shows characteristics of each proximal surfaces, according to the certified oral and maxillofacial radiologists' consensus.

	Frequency	Percent	Cumulative Percent
Sound	116	58.0	58.0
Caries at outer 1/2 of enamel	31	15.5	73.5
Caries at inner 1/2 of enamel	29	14.5	88.0
Caries into dentine	24	12.0	100.0
Total	**200**	**100.0**	

Seven observers from three different departments were referred to as “Rad_1”, “Rad_2”, “Rad_3”, “Oper_1”, “Oper_2”, “GP_1” and “GP_2”. Inter-observer agreement ranged from “moderate” to “almost perfect” (0.417 - 0.836), consisting of 9, 11 and 1 value in “moderate”, “substantial” and “almost perfect” strength, respectively.

Intra-observer agreement also ranged from “moderate” to “almost perfect” (0.496 - 0.903). Strength of agreement according to kappa value proposed by Landis and Koch (33), linear weighted kappa value between each pair of observer as well as intra-observer agreement are shown in Table 7 - 9.

Table 7 shows Landis and Koch’s strength of agreement according to kappa value.

Kappa value	**Strength of agreement**
<0.00	Poor
0.00-0.20	Slight
0.21-0.40	Fair
0.41-0.60	Moderate
0.61-0.80	Substantial
0.81-1.00	Almost perfect

Table 8 shows linear-weighted kappa values. (± standard error) and 95% confidence interval for inter-observer agreement

(p-value < 0.0001 for all kappa values)

Observer	Rad_2	Rad_3	Oper_1	Oper_2	GP_1	GP_2
Rad_1	0.481 (± 0.024) (0.434 - 0.529)	0.417 (± 0.024) (0.370 - 0.464)	0.535 (± 0.022) (0.492 - 0.579)	0.434 (± 0.025) (0.385 - 0.484)	0.482 (± 0.022) (0.439 - 0.526)	0.441 (± 0.025) (0.391 - 0.490)
Rad_2		0.611 (± 0.025) (0.562 - 0.661)	0.768 (± 0.020) (0.728 - 0.809)	0.616 (± 0.030) (0.557 - 0.676)	0.792 (± 0.021) (0.750 - 0.833)	0.656 (± 0.029) (0.599 - 0.713)
Rad_3			0.595 (± 0.026) (0.545 - 0.645)	0.417 (± 0.028) (0.362 - 0.472)	0.632 (± 0.026) (0.581 - 0.683)	0.456 (± 0.029) (0.400 - 0.513)
Oper_1				0.627 (± 0.029) (0.570 - 0.683)	0.778 (± 0.021) (0.737 - 0.819)	0.655 (± 0.028) (0.599 - 0.710)
Oper_2					0.673 (± 0.031) (0.612 - 0.734)	0.836 (± 0.022) (0.792 - 0.880)
GP_1						0.702 (± 0.030) (0.643 - 0.761)

Table 9 shows linear-weighted kappa values (± standard error) and 95% confidence interval for intra-observer agreement. (p-value < 0.0001 for all kappa values)

Observers	Kappa (± standard error)	95% Confidence interval
Rad_1	0.496 (± 0.097)	0.306 - 0.685
Rad_2	0.683 (± 0.091)	0.505 - 0.861
Rad_3	0.608 (± 0.086)	0.441 - 0.776
Oper_1	0.788 (± 0.056)	0.678 - 0.898
Oper_2	0.821 (± 0.100)	0.625 - 1.017
GP_1	0.811 (± 0.080)	0.655 - 0.968
GP_2	0.903 (± 0.037)	0.831 - 0.975

For certified radiologists' rating, proximal surfaces with "sound" rating (score 1) were labelled as "0". While surfaces with "caries at outer ½ of enamel", "caries at inner ½ of enamel" and "caries into dentine" rating (score 2, 3 and 4) were labelled as "1". Whereas, for each observer's rating, proximal surfaces with "caries definitely absent", "caries probably absent" and "unsure if caries absent or present" rating (score 1, 2 and 3) were labelled as "0". While surfaces with "caries probably present" and "caries definitely present" (score 4 and 5) were labelled as "1". Using these labelled data, all 7 observers' sensitivity, specificity, accuracy, positive predictive value and negative predictive value were calculated. (Table 10 and Appendix 1.1 - 1.21)

Table 10 shows all 7 observers' sensitivity, specificity, accuracy, positive predictive value and negative predictive value from 3 image acquiring methods. (Export = group of directly exported images, Med = group of images captured from a medical-grade display, Com = group of images captured from a common display)

Observer	Sensitivity			Specificity			Accuracy			Positive Predictive Value			Negative Predictive Value		
	Export	Med	Com	Export	Med	Com	Export	Med	Com	Export	Med	Com	Export	Med	Com
Rad_1	51.19	23.81	30.95	95.69	69.83	77.59	77.00	50.50	58.00	89.58	36.36	50.00	73.03	55.86	60.81
Rad_2	71.08	35.71	32.14	97.41	66.38	77.59	86.00	53.50	58.50	95.16	43.48	50.94	82.48	58.78	61.22
Rad_3	84.52	50.00	44.05	80.17	54.31	51.72	82.00	52.50	48.50	75.53	44.21	39.78	87.74	60.00	56.07
Oper_1	69.05	34.52	30.95	100.00	67.24	69.83	87.00	53.50	53.50	100.00	43.28	42.62	81.69	58.65	58.27
Oper_2	45.24	14.29	21.43	100.00	79.31	87.93	77.00	52.00	60.00	100.00	33.33	56.25	71.60	56.10	60.71
GP_1	72.62	29.76	29.76	94.83	68.97	74.14	85.50	52.50	55.50	91.04	40.98	45.45	82.71	57.55	59.31
GP_2	52.38	19.05	25.00	98.28	70.69	82.76	79.00	49.00	58.50	95.65	32.00	51.22	74.03	54.67	60.38

Using scores of 4-point-scale from 3 certified oral radiologists as a standard, a total of 42 ROC curves from 7 observers were generated as following;

1. Twenty-one ROC curves from all observers viewing images from three image acquiring methods, considering both enamel and dentinal caries as positive results. (Figure 8)

    1.1. Seven ROC curves from all observers viewing directly exported images, considering both enamel and dentinal caries as positive results. (Appendix 2.1 and 2.2)

    1.2. Seven ROC curves from all observers viewing images captured from a medical-grade display, considering both enamel and dentinal caries as positive results. (Appendix 2.3 and 2.4)

    1.3. Seven ROC curves from all observers viewing images captured from a common display, considering both enamel and dentinal caries as positive results. (Appendix 2.5 and 2.6)

2. Twenty-one ROC curves from all observers viewing images from three image acquiring methods, considering only dentinal caries as positive results. (Figure 9)

    2.1. Seven ROC curves from all observers viewing directly exported images, considering only dentinal caries as positive results. (Appendix 2.7 and 2.8)

2.2. Seven ROC curves from all observers viewing images captured from a medical-grade display, considering only dentinal caries as positive results. (Appendix 2.9 and 2.10)

2.3. Seven ROC curves from all observers viewing images captured from a common display, considering only dentinal caries as positive results. (Appendix 2.11 and 2.12)

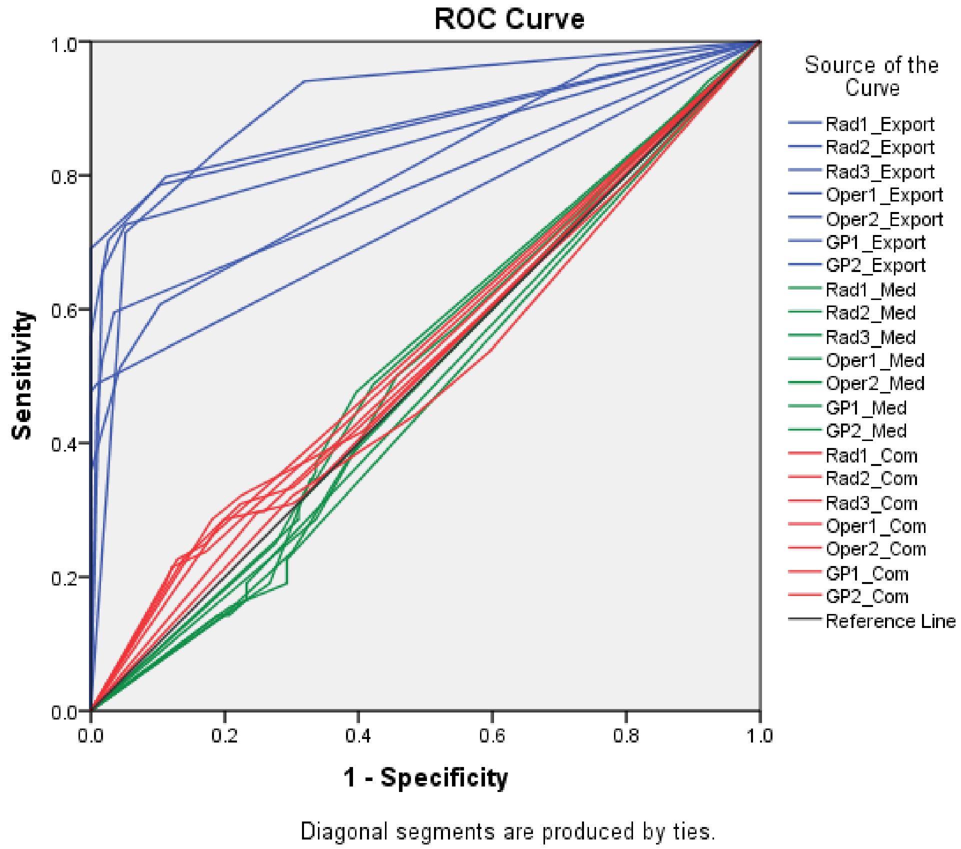
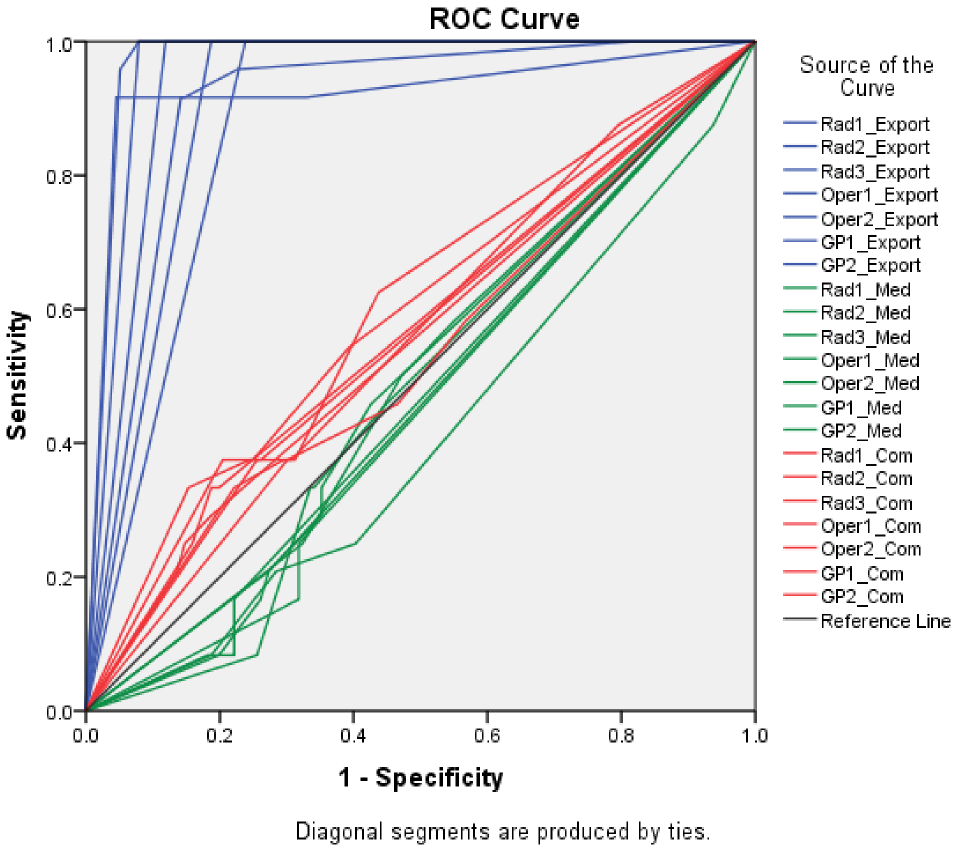


Figure 8 shows twenty-one ROC curves from all observers viewing images from three image acquiring methods, considering both enamel and dentinal caries as positive results. (Export = group of directly exported images, Med = group of images captured from a medical-grade display, Com = group of images captured from a common display)



<u>Figure 9</u> shows twenty-one ROC curves from all observers viewing images from three image acquiring methods, considering <u>only dentinal caries</u> as positive results. (Export = group of directly exported images, Med = group of images captured from a medical-grade display, Com = group of images captured from a common display)

Mean area under the curves (AUC) were compared using T-test for enamel caries and dentinal caries group and one-way ANOVA for each method of image acquiring (Table 11). For all depths of caries, the result showed significant difference between group of directly exported images and captured images, while there was no significant difference between images captured from a medical-grade display and images captured from a common display. However, when considering only dentinal caries as positive results, significant differences ($p < 0.001$) were found in all three groups. (Appendix 3.1 - 3.6)

As in depth of caries, significantly higher mean AUC in detection of dentinal caries are seen in group of directly exported images and images captured from a common display ($p = 0.004$ and 0.003, respectively). On the other hand, in group of images captured from a medical-grade display, mean AUC in detection of enamel caries is significantly higher ($p = 0.045$). (Appendix 3.7)

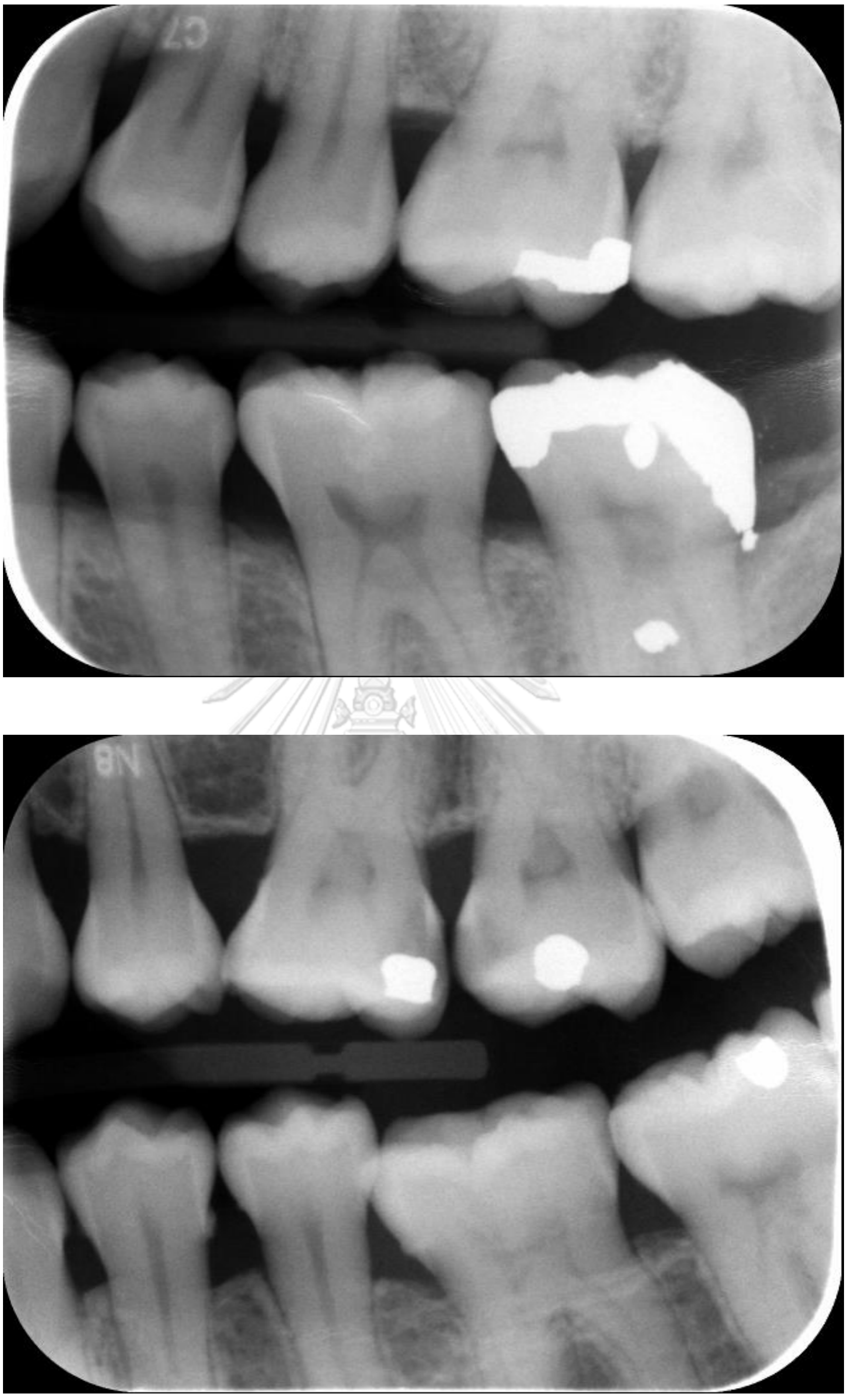
Table 11 shows mean area under ROC curves from all observers viewing images from three image acquiring methods and considering two different depths of caries as positive results. (Export = group of directly exported images, Med = group of images captured from a medical-grade display, Com = group of images captured from a common display, E&D = enamel and dentinal caries, only D = only dentinal caries)

Image acquiring methods	**Mean AUC (± standard deviation)**		
	Enamel & Dentinal caries	**Only dentinal caries**	
Export	0.834 (± 0.058)	0.927 (± 0.038)	**E&D** VS **only D**; $p = 0.004$
Med	0.494 (± 0.020)	0.464 (± 0.030)	**E&D** VS **only D**; $p = 0.045$
Com	0.521 (± 0.019)	0.565 (± 0.024)	**E&D** VS **only D**; $p = 0.003$
	Export VS **M2 & M3**; $p < 0.001$ **M2** VS **M3**; $p = 0.387$	**Export** VS **M2** VS **M3**; $p < 0.001$	

Discussion

According to previous studies (16, 17), prevalence of dentine-penetrated caries at proximal surfaces was found to be approximately 11.2 - 25.25%. In this study, 24 surfaces with dentinal caries or 12% from a total of 200 surfaces were included, which were in concordance with mentioned statistics. Also, there were 60 proximal surfaces with enamel caries and 116 sound surfaces.

Depth of caries can affect diagnostic accuracy in proximal caries detection. Generally, dentinal caries are more evident and more likely to be observed. Enamel caries, on the other hand, are usually more subtle which result in discrepancy of detection outcome. (Figure 10 and 11) The group of samples that has high proportion of dentinal to enamel caries tend to have stronger and narrower range of agreement between observers. A study (6) that included only enamel-depth caries had quite wide range of inter-observer agreement (0.239 - 0.858). While, other studies (34, 35) that sampled various depth of proximal caries had narrower range of agreement among observers (0.44 - 0.47 and 0.778 - 0.847, respectively).



<u>Figure 10 & 11</u> show different clarity between enamel caries (upper image, Tooth 24D) and dentinal caries (lower image, Tooth 26D and Tooth 27M). Both images were directly exported from PACS software.

In this study, 7 observers using the same smartphone display to evaluate proximal caries from digital bitewing radiographs showed “moderate” to “almost perfect” agreement (0.417 - 0.836). Many types of display including medical-grade displays, common displays and portable tablets were compared to assess their efficacy in proximal caries detection. Kappa values from previous researches as well as in this study were listed in Table 12.

Table 12 shows kappa values from previous studies, according to inter-observer agreements in evaluations of proximal caries from different types of display.

Study	Display	Kappa value
This study	Smartphone display	0.417 - 0.836
Abuzenada (34)	Unspecified digital display	0.44 - 0.47
Adibi et al. (35)	Printed digital film on glossy papers	0.778
	Common display	0.847
Countryman et al. (6)	First medical-grade display	0.331 - 0.797
	Second medical-grade display	0.333 - 0.811
	First tablet display	0.239 - 0.785
	Second tablet display	0.300 - 0.858
	Common display	0.383 - 0.780

From the above table, the study (35) that provided the highest kappa value sampled 240 proximal surfaces with 91 dentinal caries (37.92%). The participating observers were 2 oral and maxillofacial radiologists with at least 5 years of experience. High proportion of dentinal to enamel caries and experienced observers might contribute to this result.

Comparing with Adibi et al.'s research, Countryman's study (6) which included 3 radiology resident students with 1 - 2 years of experience showed lower kappa value. The authors also sampled 240 proximal surfaces but all of them were artificial incipient caries and enamel-depth, recurrent-like lesion, which were more difficult to determine than dentinal caries.

The lowest kappa value was reported in the study of Abuzenada (34). One radiologist and one dentist specialized in operative dentistry evaluated 152 digital bitewing radiographs without time constraint. The amount of proximal surfaces needed to be assessed was unspecified. However, the more films needed to be assessed, the more hours required in interpretation session. Such long session could induce eye strain and compromise dentists' performance (36).

Proximal surfaces sampled in this study had less percentage of dentinal caries than Adibi et al.'s study, resulting in wider range of calculated kappa value but not as wide as Countryman et al.'s investigation that included only artificial incipient caries and recurrent-like lesion.

Dentists specialized in operative dentistry, oral radiologists and general practitioners were selected in this study due to their constant experience with caries detection. Previous studies (5, 6, 10, 11) also recruited these specialists. Langlais et al.

(32) compared inter-observer agreement of 34 dentists from three different field of dentistry using kappa statistics (13 dentists from the Department of General Practice, 8 dentists from the Department of Operative Dentistry and 13 dentists from the Department of Dental Diagnostic Science). According to the result, highest kappa value was obtained from a group of dentists from the Department of Dental Diagnostic Science. The authors suggested that this was due to the fact that dentists working in the Department of Dental Diagnostic Science have received more radiology training than the others. However, two general practitioners participating in this research provided the strongest inter-observer agreement (0.702 ± 0.030), over two selected dentists specialized in operative dentistry (0.627 ± 0.029) and three oral radiologists (0.481 (± 0.024), 0.417 (± 0.024) and 0.611 (± 0.025)). This might due to difference in numbers of participating dentists, which were higher in the mentioned study. Low number of observers could not represent the whole population and might lead to discrepancy between results of each investigation.

Other than dental specialty, many aspects of observers were studied to determine if they had any effects on radiographic interpretation and diagnostic accuracy. There was a study (37) that compared between male and female dentists in proximal caries detection. The result revealed no gender-specific differences. The same research also compared experiences of the observers, which can be related to age. The authors found that chance of correct assessment was four times greater in older dentists than in younger ones. Still, experience alone might not guarantee better performance, as the observer with the longest experience (43 years) in this study did not obtain the highest accuracy in any image acquiring method.

As of visual acuity, limited studies were found to be addressing the issue (38). A study performed in a dental school in New Zealand (39) had the teachers complete a self-assessed questionnaire about conditions and satisfactory of their eyesight for their dental practice. The result showed that 92% of the teacher considered their vision to be sufficient. In this study, all 7 observers had either normal eyesight or been equipped with appropriate corrective lens.

Evaluation of captured images provided significantly less accuracy in proximal caries detection, compared to assessment using directly exported images from PACS software. Several factors can influence the results. Such factors include hand shake, ambient light, angle and distance used in image capturing, moiré pattern caused by discrepancy between digital sensor grids of a smartphone camera and a displayed monitor, etc. In this study, a special holding was set to hold a smartphone in place with fixed angulation during image capturing. However, in real clinical settings, such holding is rarely used. Taken photos were usually affected by numerous subjective factors (3). Dentists interpreting captured images should be aware of these factors due to the fact that they can drastically affect the diagnostic accuracy.

In this study, the same image acquiring method was used to capture every radiograph from both displays. However, in some images with originally high brightness, using the same capturing method resulted in even more high brightness and contrast, especially when the image was captured from the selected common display (Figure 12). This may due to reflectiveness of the display. A medical-grade display is usually coated with anti-reflective substance and equipped with optical glass that can reduce screen reflection (40).

Another possible reason is from an effect of exposure compensation which is an automatic function installed in digital cameras to level overall image exposure. When a camera is focused on a dark area, the camera automatically increases the exposure to compensate for the blackness at the focus point. This results in an overexposed image. On the other hand, if a camera is focused on a bright area, the exposure is therefore decreased and the resultant image is underexposed (41). An example of exposure change when switching between two different focus points are shown in Figure 13.

Due to differences in screen size and distance used in image capturing, original images that were captured from a smaller common display covered more area of white wall behind the monitor than images captured from a bigger medical-grade display (Figure 14). When a dark area at the center of the smartphone screen was tapped to determine the focus point, higher proportion of bright to dark area in images captured from a common display may contribute to overall overexposed results. The most proper setting for image capturing from a medical-grade and common display is yet to be determined and requires further investigation.

(a)

(b)

(c)

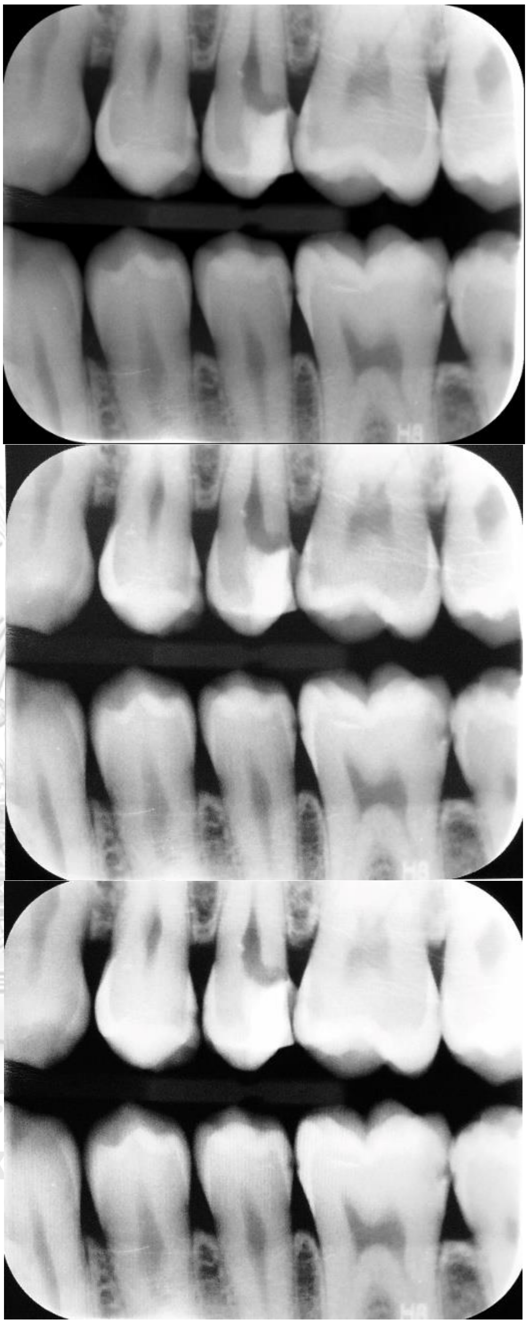
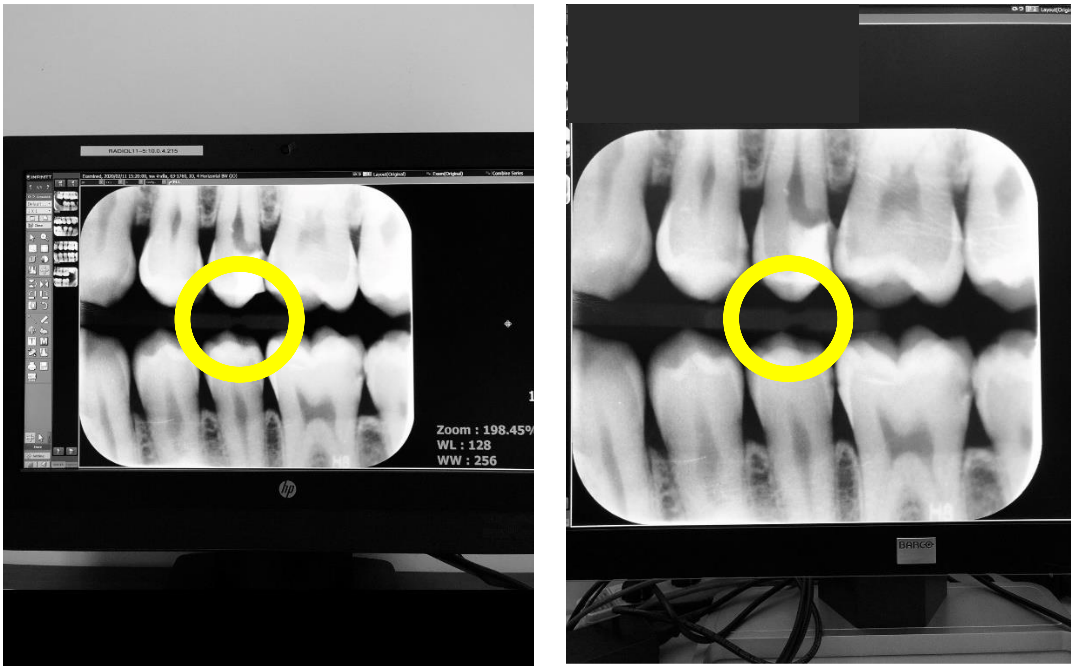


Figure 12 shows three images of sampled digital bitewing radiograph from three different image acquiring methods. Much higher brightness and contrast are observed in the image captured from a common display. ((a) image directly exported from PACS software, (b) image captured from a medical-grade display, (c) image captured from a common display)

(a)

(b)

Figure 13 shows exposure change when switching between two different focus points (stars) while using "Mono" filter installed in an iPhone 8 plus. ((a) focusing on the center of the display (dark area), (b) focusing on the white wall behind the display (bright area))



(a) (b)

Figure 14 shows two areas at the center of the smartphone screen that were tapped before image capturing from two different displays to determine the focus points (within circles). Proportion of bright to dark area in images captured from a common display (a) is higher than those captured from a medical-grade display (b), resulting in higher exposure in resultant images.

Conclusion

Nowadays, emerging of novel smart devices and digital gadgets with inventive technologies influences every generation's lifestyle. High-resolution monitors can display images with precise details. Digital cameras as well as internet feature installed in every smartphone can capture and transfer data for communication within little amount of time. Specialists from various fields of dentistry, along with general practitioners, can greatly benefit from these innovations and utilize them in disease diagnosis and treatment planning. However, according to the results from this study, detection of proximal caries should be done using directly exported images from PACS software. Captured images should be evaluated with utmost caution since considerable factors can affect image quality.

APPENDIX

APPENDIX (Cont.)

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<u>Appendix 1.1</u> shows a cross tabulation of data from the first radiologist (Rad_1), viewing <u>directly exported</u> images.

Rad_1 * Caries_Export (1=0 / 2,3,4=1) Cross tabulation

			Caries (1=0 / 2,3,4=1)		Total
			No caries	With caries	
Rad_1	0	Count	111	41	152
		% within Rad_1	73.0%	27.0%	100.0%
	1	Count	5	43	48
		% within Rad_1	10.4%	89.6%	100.0%
Total		**Count**	**116**	**84**	**200**
		% within Rad_1	**58.0%**	**42.0%**	**100.0%**

<u>Appendix 1.2</u> shows a cross tabulation of data from the second radiologist (Rad_2), viewing <u>directly exported</u> images.

Rad_2 * Caries_ Export (1=0 / 2,3,4=1) Cross tabulation

			Caries (1=0 / 2,3,4=1)		Total
			No caries	With caries	
Rad_2	0	Count	113	25	138
		% within Rad_2	81.9%	18.1%	100.0%
	1	Count	3	59	62
		% within Rad_2	4.8%	95.2%	100.0%
Total		**Count**	**116**	**84**	**200**
		% within Rad_2	**58.0%**	**42.0%**	**100.0%**

<u>Appendix 1.3</u> shows a cross tabulation of data from the third radiologist (Rad_3), viewing <u>directly exported</u> images.

Rad_3 * Caries_ Export (1=0 / 2,3,4=1) Cross tabulation

			Caries (1=0 / 2,3,4=1)		Total
			No caries	With caries	
Rad_3	0	Count	93	13	106
		% within Rad_3	87.7%	12.3%	100.0%
	1	Count	23	71	94
		% within Rad_3	24.5%	75.5%	100.0%
Total		**Count**	**116**	**84**	**200**
		% within Rad_3	**58.0%**	**42.0%**	**100.0%**

<u>Appendix 1.4</u> shows a cross tabulation of data from the first dentist specialized in operative dentistry (Oper_1), viewing <u>directly exported</u> images.

Oper_1 * Caries_ Export (1=0 / 2,3,4=1) Cross tabulation

			Caries (1=0 / 2,3,4=1)		Total
			No caries	With caries	
Oper_1	0	Count	116	26	142
		% within Oper_1	81.7%	18.3%	100.0%
	1	Count	0	58	58
		% within Oper_1	0.0%	100.0%	100.0%
Total		**Count**	**116**	**84**	**200**
		% within Oper_1	**58.0%**	**42.0%**	**100.0%**

Appendix 1.5 shows a cross tabulation of data from the second dentist specialized in operative dentistry (Oper_2), viewing directly exported images.

Oper_2 * Caries_ Export (1=0 / 2,3,4=1) Cross tabulation

			Caries (1=0 / 2,3,4=1)		Total
			No caries	With caries	
Oper_2	0	Count	116	46	162
		% within Oper_2	71.6%	28.4%	100.0%
	1	Count	0	38	38
		% within Oper_2	0.0%	100.0%	100.0%
Total		**Count**	**116**	**84**	**200**
		% within Oper_2	**58.0%**	**42.0%**	**100.0%**

Appendix 1.6 shows a cross tabulation of data from the first general practitioner (GP_1), viewing directly exported images.

GP_1 * Caries_ Export (1=0 / 2,3,4=1) Cross tabulation

			Caries (1=0 / 2,3,4=1)		Total
			No caries	With caries	
GP_1	0	Count	110	23	133
		% within GP_1	82.7%	17.3%	100.0%
	1	Count	6	61	67
		% within GP_1	9.0%	91.0%	100.0%
Total		**Count**	**116**	**84**	**200**
		% within GP_1	**58.0%**	**42.0%**	**100.0%**

Appendix 1.7 shows a cross tabulation of data from the second general practitioner (GP_2), viewing directly exported images.

GP_2 * Caries_ Export (1=0 / 2,3,4=1) Cross tabulation

			Caries (1=0 / 2,3,4=1)		Total
			No caries	With caries	
GP_2	0	Count	114	40	154
		% within GP_2	74.0%	26.0%	100.0%
	1	Count	2	44	46
		% within GP_2	4.3%	95.7%	100.0%
Total		**Count**	**116**	**84**	**200**
		% within GP_2	**58.0%**	**42.0%**	**100.0%**

Appendix 1.8 shows a cross tabulation of data from the first radiologist (Rad_1), viewing images captured from a medical-grade display.

Rad_1 * Caries_Med (1=0 / 2,3,4=1) Cross tabulation

			Caries (1=0 / 2,3,4=1)		Total
			No caries	With caries	
Rad_1	0	Count	81	64	145
		% within Rad_1	55.9%	44.1%	100.0%
	1	Count	35	20	55
		% within Rad_1	63.6%	36.4%	100.0%
Total		**Count**	**116**	**84**	**200**
		% within Rad_1	**58.0%**	**42.0%**	**100.0%**

Appendix 1.9 shows a cross tabulation of data from the second radiologist (Rad_2), viewing images captured from a medical-grade display.

Rad_2 * Caries_ Med (1=0 / 2,3,4=1) Cross tabulation

			Caries (1=0 / 2,3,4=1)		Total
			No caries	With caries	
Rad_2	0	Count	77	54	131
		% within Rad_2	58.8%	41.2%	100.0%
	1	Count	39	30	69
		% within Rad_2	56.5%	43.5%	100.0%
Total		**Count**	**116**	**84**	**200**
		% within Rad_2	**58.0%**	**42.0%**	**100.0%**

Appendix 1.10 shows a cross tabulation of data from the third radiologist (Rad_3), viewing images captured from a medical-grade display.

Rad_3 * Caries_ Med (1=0 / 2,3,4=1) Cross tabulation

			Caries (1=0 / 2,3,4=1)		Total
			No caries	With caries	
Rad_3	0	Count	63	42	105
		% within Rad_3	60.0%	40.0%	100.0%
	1	Count	53	42	95
		% within Rad_3	55.8%	44.2%	100.0%
Total		**Count**	**116**	**84**	**200**
		% within Rad_3	**58.0%**	**42.0%**	**100.0%**

Appendix 1.11 shows a cross tabulation of data from the first dentist specialized in operative dentistry (Oper_1), viewing images captured from a medical-grade display.

Oper_1 * Caries_ Med (1=0 / 2,3,4=1) Cross tabulation

			Caries (1=0 / 2,3,4=1) No caries	Caries (1=0 / 2,3,4=1) With caries	Total
Oper_1	0	Count	78	55	133
		% within Oper_1	58.6%	41.4%	100.0%
	1	Count	38	29	67
		% within Oper_1	56.7%	43.3%	100.0%
Total		**Count**	**116**	**84**	**200**
		% within Oper_1	**58.0%**	**42.0%**	**100.0%**

Appendix 1.12 shows a cross tabulation of data from the second dentist specialized in operative dentistry (Oper_2), viewing images captured from a medical-grade display.

Oper_2 * Caries_ Med (1=0 / 2,3,4=1) Cross tabulation

			Caries (1=0 / 2,3,4=1) No caries	Caries (1=0 / 2,3,4=1) With caries	Total
Oper_2	0	Count	92	72	164
		% within Oper_2	56.1%	43.9%	100.0%
	1	Count	24	12	36
		% within Oper_2	66.7%	33.3%	100.0%
Total		**Count**	**116**	**84**	**200**
		% within Oper_2	**58.0%**	**42.0%**	**100.0%**

<u>Appendix 1.13</u> shows a cross tabulation of data from the first general practitioner (GP_1), viewing <u>images captured from a medical-grade display</u>.

GP_1 * Caries_ Med (1=0 / 2,3,4=1) Cross tabulation

			Caries (1=0 / 2,3,4=1)		Total
			No caries	With caries	
GP_1	0	Count	80	59	139
		% within GP_1	57.6%	42.4%	100.0%
	1	Count	36	25	61
		% within GP_1	59.0%	41.0%	100.0%
Total		**Count**	**116**	**84**	**200**
		% within GP_1	**58.0%**	**42.0%**	**100.0%**

<u>Appendix 1.14</u> shows a cross tabulation of data from the second general practitioner (GP_2), viewing <u>images captured from a medical-grade display</u>.

GP_2 * Caries_ Med (1=0 / 2,3,4=1) Cross tabulation

			Caries (1=0 / 2,3,4=1)		Total
			No caries	With caries	
GP_2	0	Count	82	68	150
		% within GP_2	54.7%	45.3%	100.0%
	1	Count	34	16	50
		% within GP_2	68.0%	32.0%	100.0%
Total		**Count**	**116**	**84**	**200**
		% within GP_2	**58.0%**	**42.0%**	**100.0%**

Appendix 1.15 shows a cross tabulation of data from the first radiologist (Rad_1), viewing images captured from a common display.

Rad_1 * Caries_Com (1=0 / 2,3,4=1) Cross tabulation

			Caries (1=0 / 2,3,4=1)		Total
			No caries	With caries	
Rad_1	0	Count	90	58	148
		% within Rad_1	60.8%	39.2%	100.0%
	1	Count	26	26	52
		% within Rad_1	50.0%	50.0%	100.0%
Total		**Count**	**116**	**84**	**200**
		% within Rad_1	**58.0%**	**42.0%**	**100.0%**

Appendix 1.16 shows a cross tabulation of data from the second radiologist (Rad_2), viewing images captured from a common display.

Rad_2 * Caries_ Com (1=0 / 2,3,4=1) Cross tabulation

			Caries (1=0 / 2,3,4=1)		Total
			No caries	With caries	
Rad_2	0	Count	90	57	147
		% within Rad_2	61.2%	38.8%	100.0%
	1	Count	26	27	53
		% within Rad_2	49.1%	50.9%	100.0%
Total		**Count**	**116**	**84**	**200**
		% within Rad_2	**58.0%**	**42.0%**	**100.0%**

<u>Appendix 1.17</u> shows a cross tabulation of data from the third radiologist (Rad_3), viewing images captured from a common display.

Rad_3 * Caries_ Com (1=0 / 2,3,4=1) Cross tabulation

			Caries (1=0 / 2,3,4=1)		Total
			No caries	With caries	
Rad_3	0	Count	60	47	107
		% within Rad_3	56.1%	43.9%	100.0%
	1	Count	56	37	93
		% within Rad_3	60.2%	39.8%	100.0%
Total		**Count**	**116**	**84**	**200**
		% within Rad_3	**58.0%**	**42.0%**	**100.0%**

<u>Appendix 1.18</u> shows a cross tabulation of data from the first dentist specialized in operative dentistry (Oper_1), viewing images captured from a common display.

Oper_1 * Caries_ Com (1=0 / 2,3,4=1) Cross tabulation

			Caries (1=0 / 2,3,4=1)		Total
			No caries	With caries	
Oper_1	0	Count	81	58	139
		% within Oper_1	58.3%	41.7%	100.0%
	1	Count	35	26	61
		% within Oper_1	57.4%	42.6%	100.0%
Total		**Count**	**116**	**84**	**200**
		% within Oper_1	**58.0%**	**42.0%**	**100.0%**

Appendix 1.19 shows a cross tabulation of data from the second dentist specialized in operative dentistry (Oper_2), viewing images captured from a common display.

Oper_2 * Caries_ Com (1=0 / 2,3,4=1) Cross tabulation

			Caries (1=0 / 2,3,4=1)		Total
			No caries	With caries	
Oper_2	0	Count	102	66	168
		% within Oper_2	60.7%	39.3%	100.0%
	1	Count	14	18	32
		% within Oper_2	43.8%	56.3%	100.0%
Total		**Count**	**116**	**84**	**200**
		% within Oper_2	**58.0%**	**42.0%**	**100.0%**

Appendix 1.20 shows a cross tabulation of data from the first general practitioner (GP_1), viewing images captured from a common display.

GP_1 * Caries_ Com (1=0 / 2,3,4=1) Cross tabulation

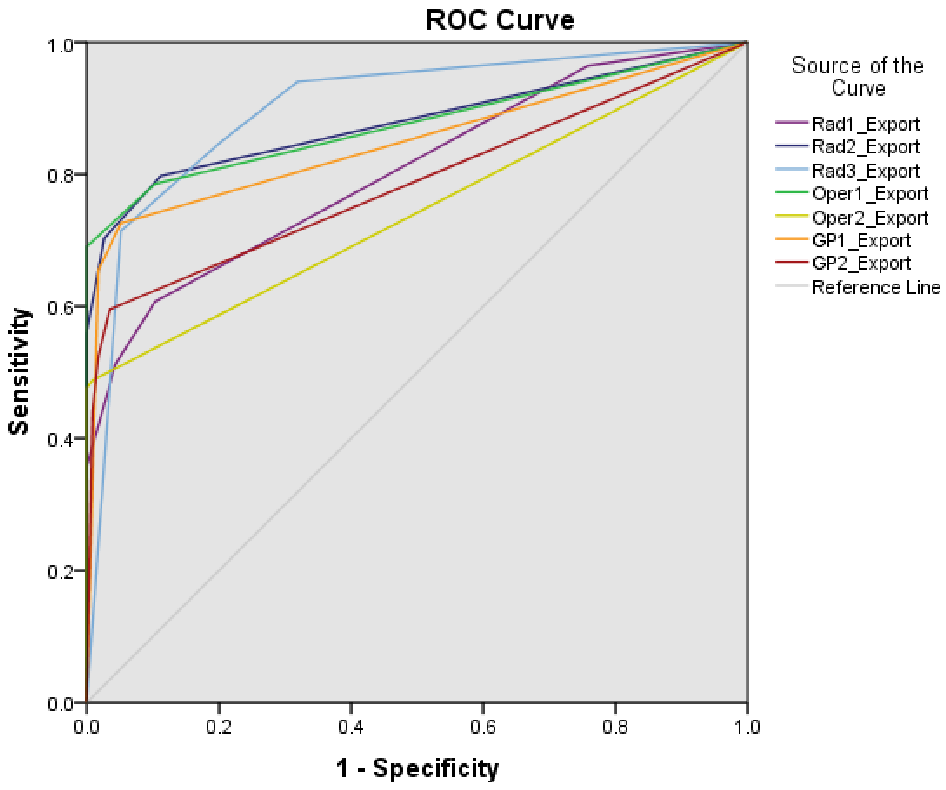
			Caries (1=0 / 2,3,4=1)		Total
			No caries	With caries	
GP_1	0	Count	86	59	145
		% within GP_1	59.3%	40.7%	100.0%
	1	Count	30	25	55
		% within GP_1	54.5%	45.5%	100.0%
Total		**Count**	**116**	**84**	**200**
		% within GP_1	**58.0%**	**42.0%**	**100.0%**

Appendix 1.21 shows a cross tabulation of data from the second general practitioner (GP_2), viewing images captured from a common display.

GP_2 * Caries_ Com (1=0 / 2,3,4=1) Cross tabulation

			Caries (1=0 / 2,3,4=1)		Total
			No caries	With caries	
GP_2	0	Count	96	63	159
		% within GP_2	60.4%	39.6%	100.0%
	1	Count	20	21	41
		% within GP_2	48.8%	51.2%	100.0%
Total		**Count**	**116**	**84**	**200**
		% within GP_2	**58.0%**	**42.0%**	**100.0%**

<u>Appendix 2.1</u> shows seven ROC curves from all observers viewing <u>directly exported images</u>, considering <u>both enamel and dentinal caries</u> as positive results.



Diagonal segments are produced by ties.

Appendix 2.2 shows seven areas under ROC curves from all observers viewing directly exported images, considering both enamel and dentinal caries as positive results.

Area Under the Curve

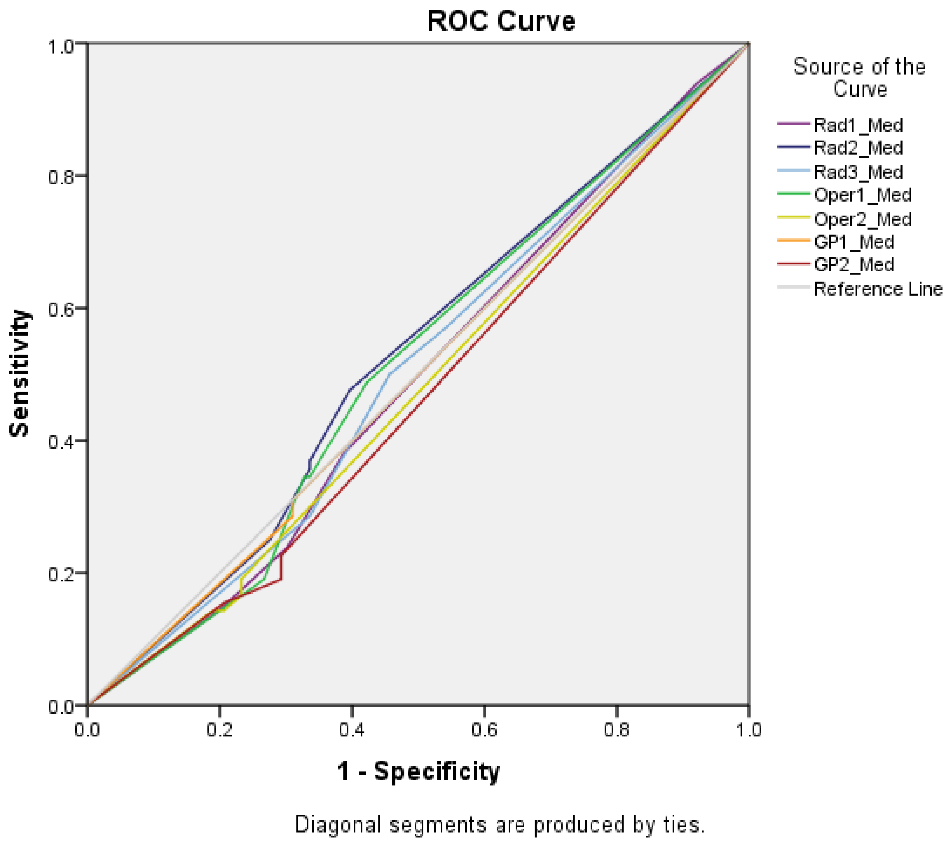
Test Result Variable(s)	Area	Std. Error[a]	Asymptotic Sig.[b]	Asymptotic 95% Confidence Interval	
				Lower Bound	Upper Bound
Rad1_Export	.804	.032	.000	.741	.868
Rad2_Export	.879	.028	.000	.824	.934
Rad3_Export	.901	.023	.000	.856	.947
Oper1_Export	.877	.029	.000	.821	.933
Oper2_Export	.742	.038	.000	.667	.817
GP1_Export	.848	.031	.000	.786	.909
GP2_Export	.786	.036	.000	.716	.856

The test result variable(s): Rad1_Export, Rad2_Export, Rad3_Export, Oper1_Export, Oper2_Export, GP1_Export, GP2_Export has at least one tie between the positive actual state group and the negative actual state group. Statistics may be biased.

a. Under the nonparametric assumption

b. Null hypothesis: true area = 0.5

Appendix 2.3 shows seven ROC curves from all observers viewing images captured from a medical-grade display, considering both enamel and dentinal caries as positive results.



Appendix 2.4 shows seven areas under ROC curves from all observers viewing images captured from a medical-grade display, considering both enamel and dentinal caries as positive results.

Area Under the Curve

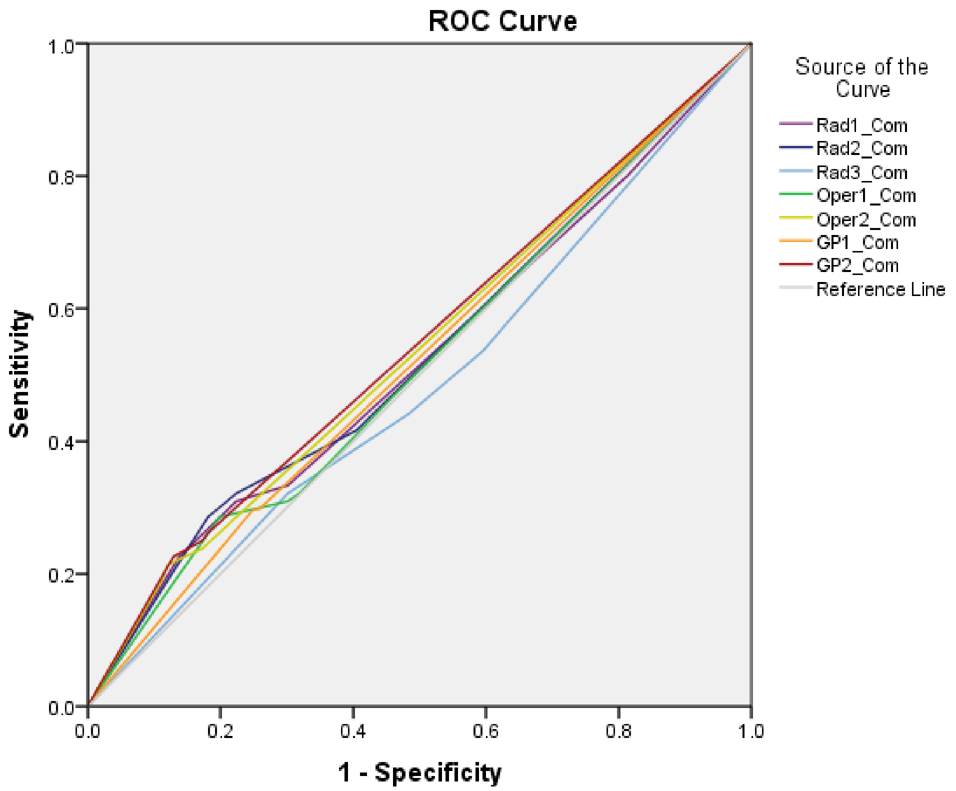
Test Result Variable(s)	Area	Std. Error[a]	Asymptotic Sig.[b]	Asymptotic 95% Confidence Interval	
				Lower Bound	Upper Bound
Rad1_Med	.489	.041	.790	.408	.569
Rad2_Med	.524	.041	.567	.443	.605
Rad3_Med	.501	.041	.988	.420	.581
Oper1_Med	.510	.041	.804	.430	.591
Oper2_Med	.477	.041	.574	.396	.557
GP1_Med	.496	.041	.921	.415	.577
GP2_Med	.464	.041	.389	.384	.545

The test result variable(s): Rad1_Med, Rad2_Med, Rad3_Med, Oper1_Med, Oper2_Med, GP1_Med, GP2_Med has at least one tie between the positive actual state group and the negative actual state group. Statistics may be biased.

a. Under the nonparametric assumption

b. Null hypothesis: true area = 0.5

<u>Appendix 2.5</u> shows seven ROC curves from all observers viewing images captured from a common display, considering both enamel and dentinal caries as positive results.



Diagonal segments are produced by ties.

Appendix 2.6 shows seven areas under ROC curves from all observers viewing images captured from a common display, considering both enamel and dentinal caries as positive results.

Area Under the Curve

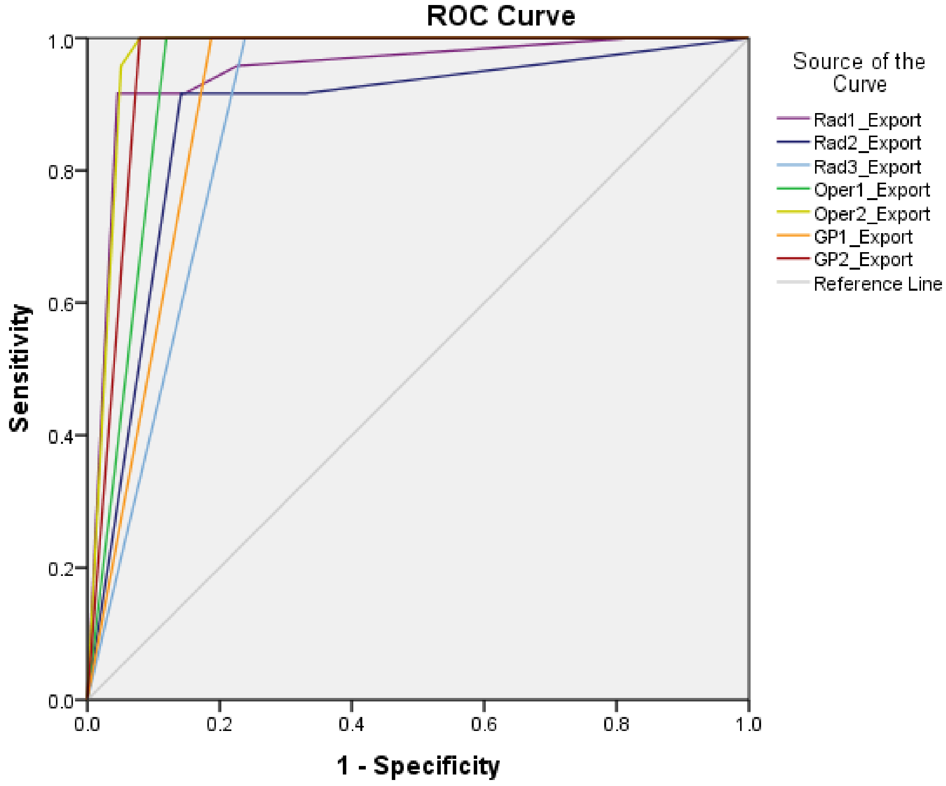
Test Result Variable(s)	Area	Std. Error[a]	Asymptotic Sig.[b]	Asymptotic 95% Confidence Interval	
				Lower Bound	Upper Bound
Rad1_Com	.522	.042	.601	.439	.604
Rad2_Com	.527	.042	.513	.445	.609
Rad3_Com	.483	.042	.687	.401	.565
Oper1_Com	.516	.042	.693	.434	.598
Oper2_Com	.536	.042	.380	.455	.618
GP1_Com	.521	.042	.616	.439	.602
GP2_Com	.544	.042	.291	.462	.626

The test result variable(s): Rad1_Com, Rad2_Com, Rad3_Com, Oper1_Com, Oper2_Com, GP1_Com, GP2_Com has at least one tie between the positive actual state group and the negative actual state group. Statistics may be biased.

a. Under the nonparametric assumption

b. Null hypothesis: true area = 0.5

<u>Appendix 2.7</u> shows seven ROC curves from all observers viewing <u>directly exported images</u>, considering <u>only dentinal caries</u> as positive results.



Diagonal segments are produced by ties.

Appendix 2.8 shows seven areas under ROC curves from all observers viewing directly exported images, considering only dentinal caries as positive results.

Area Under the Curve

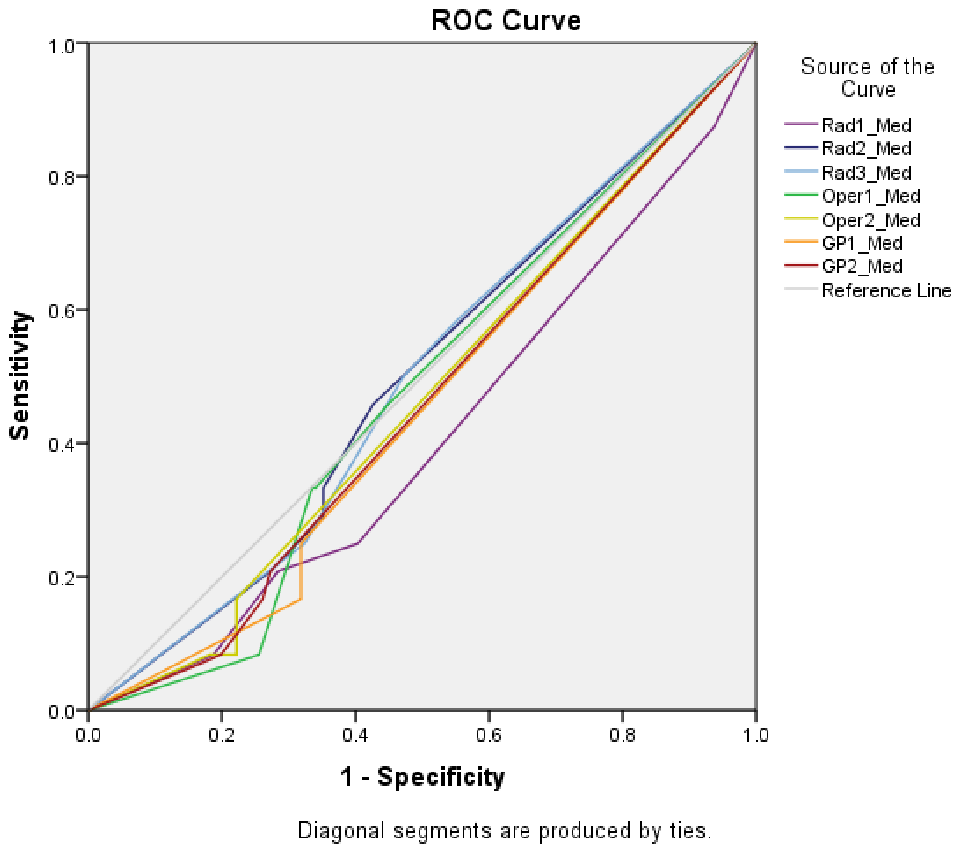
Test Result Variable(s)	Area	Std. Error[a]	Asymptotic Sig.[b]	Asymptotic 95% Confidence Interval	
				Lower Bound	Upper Bound
Rad1_Export	.949	.025	.000	.901	.998
Rad2_Export	.879	.039	.000	.802	.957
Rad3_Export	.881	.024	.000	.834	.928
Oper1_Export	.940	.016	.000	.909	.972
Oper2_Export	.973	.011	.000	.952	.993
GP1_Export	.906	.021	.000	.865	.947
GP2_Export	.960	.013	.000	.935	.986

The test result variable(s): Rad1_Export, Rad2_Export, Rad3_Export, Oper1_Export, Oper2_Export, GP1_Export, GP2_Export has at least one tie between the positive actual state group and the negative actual state group. Statistics may be biased.

a. Under the nonparametric assumption

b. Null hypothesis: true area = 0.5

Appendix 2.9 shows seven ROC curves from all observers viewing images captured from a medical-grade display, considering only dentinal caries as positive results.



Appendix 2.10 shows seven areas under ROC curves from all observers viewing images captured from a medical-grade display, considering only dentinal caries as positive results.

Area Under the Curve

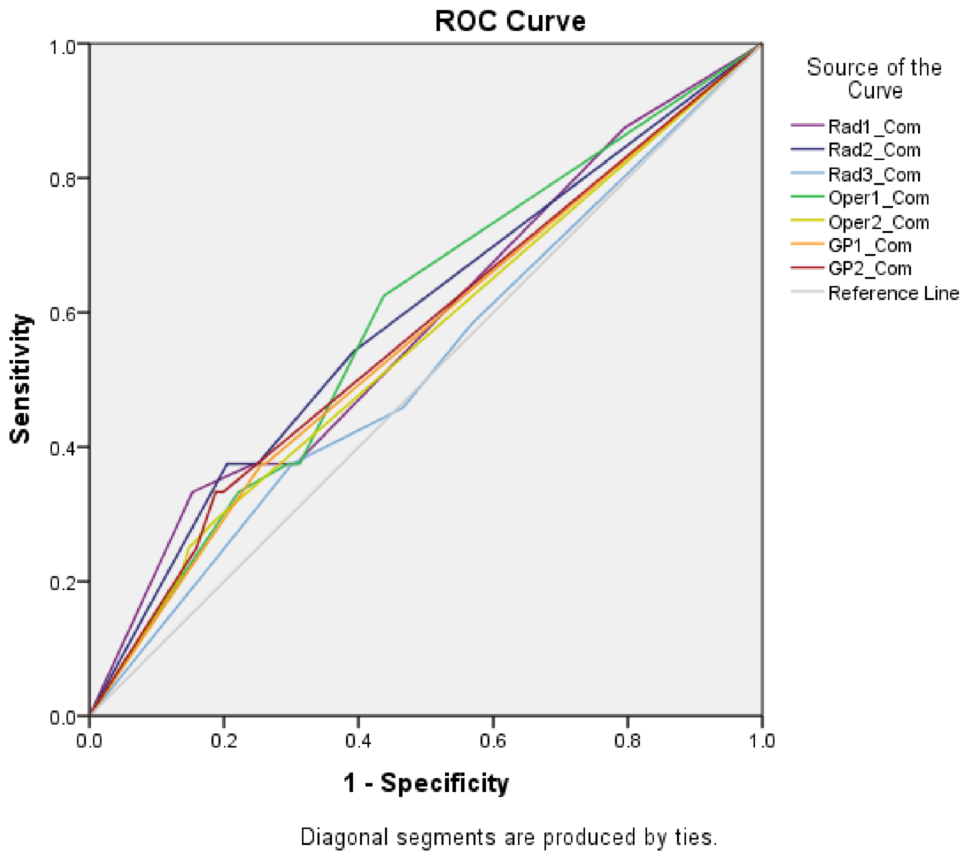
Test Result Variable(s)	Area	Std. Error[a]	Asymptotic Sig.[b]	Asymptotic 95% Confidence Interval	
				Lower Bound	Upper Bound
Rad1_Med	.408	.061	.145	.290	.527
Rad2_Med	.496	.060	.949	.378	.614
Rad3_Med	.494	.060	.928	.377	.612
Oper1_Med	.474	.057	.676	.361	.586
Oper2_Med	.465	.060	.578	.348	.582
GP1_Med	.453	.059	.452	.337	.568
GP2_Med	.458	.059	.501	.342	.573

The test result variable(s): Rad1_Med, Rad2_Med, Rad3_Med, Oper1_Med, Oper2_Med, GP1_Med, GP2_Med has at least one tie between the positive actual state group and the negative actual state group. Statistics may be biased.

a. Under the nonparametric assumption

b. Null hypothesis: true area = 0.5

<u>Appendix 2.11</u> shows seven ROC curves from all observers viewing <u>images captured from a common display</u>, considering <u>only dentinal caries</u> as positive results.



Appendix 2.12 shows seven areas under ROC curves from all observers viewing images captured from a common display, considering only dentinal caries as positive results.

Area Under the Curve

Test Result Variable(s)	Area	Std. Error[a]	Asymptotic Sig.[b]	Asymptotic 95% Confidence Interval	
				Lower Bound	Upper Bound
Rad1_Com	.578	.065	.213	.452	.705
Rad2_Com	.589	.065	.157	.463	.716
Rad3_Com	.520	.065	.748	.393	.647
Oper1_Com	.589	.061	.157	.469	.709
Oper2_Com	.552	.065	.406	.425	.680
GP1_Com	.558	.065	.358	.431	.685
GP2_Com	.566	.065	.294	.438	.694

The test result variable(s): Rad1_Com, Rad2_Com, Rad3_Com, Oper1_Com, Oper2_Com, GP1_Com, GP2_Com has at least one tie between the positive actual state group and the negative actual state group. Statistics may be biased.

a. Under the nonparametric assumption

b. Null hypothesis: true area = 0.5

Appendix 3.1 shows comparison of mean area under ROC curves from all observers, according to image acquiring methods. Both enamel and dentinal caries are considered as positive results. (Group E = directly exported images, Group M = images captured from a medical-grade display, Group C = images captured from a common display)

Descriptives

AUC_E

Group	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
E	7	.83386	.058062	.021945	.78016	.88756	.742	.901
M	7	.49443	.020090	.007593	.47585	.51301	.464	.524
C	7	.52129	.019405	.007335	.50334	.53923	.483	.544
Total	21	.61652	.161769	.035301	.54289	.69016	.464	.901

Appendix 3.2 shows significant difference between groups of each image acquiring method. Both enamel and dentinal caries are considered as positive results.

ANOVA

AUC_E

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.498	2	.249	180.115	.000
Within Groups	.025	18	.001		
Total	.523	20			

Appendix 3.3 shows significant difference ($p < 0.001$) between group of directly exported images (Group E) and captured images (Group M and C), while there was no significant difference ($p = 0.387$) between images captured from a medical-grade display (Group M) and images captured from a common display (Group C).

Multiple Comparisons

Dependent Variable: AUC_E

Tukey HSD

(I) AUC_ Method	(J) AUC_ Method	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
E	M	.339429*	.019884	.000	.28868	.39018
	C	.312571*	.019884	.000	.26182	.36332
M	E	-.339429*	.019884	.000	-.39018	-.28868
	C	-.026857	.019884	.387	-.07760	.02389
C	E	-.312571*	.019884	.000	-.36332	-.26182
	M	.026857	.019884	.387	-.02389	.07760

*. The mean difference is significant at the 0.05 level.

<u>Appendix 3.4</u> shows comparison of mean area under ROC curves from all observers, according to image acquiring methods. Only dentinal caries are considered as positive results. (Group E = directly exported images, Group M = images captured from a medical-grade display, Group C = images captured from a common display)

Descriptives

AUC_D

Group	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
E	7	.92686	.038120	.014408	.89160	.96211	.879	.973
M	7	.46400	.029771	.011253	.43647	.49153	.408	.496
C	7	.56457	.024371	.009211	.54203	.58711	.520	.589
Total	21	.65181	.205832	.044916	.55812	.74550	.408	.973

<u>Appendix 3.5</u> shows significant difference between groups of each image acquiring method. Only dentinal caries are considered as positive results.

ANOVA

AUC_D

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.830	2	.415	424.284	.000
Within Groups	.018	18	.001		
Total	.847	20			

Appendix 3.6 shows significant difference ($p < 0.001$) among all three groups.

Multiple Comparisons

Dependent Variable: AUC_D

Tukey HSD

(I) AUC_ Method	(J) AUC_ Method	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
E	M	.462857*	.016714	.000	.42020	.50552
	C	.362286*	.016714	.000	.31963	.40494
M	E	-.462857*	.016714	.000	-.50552	-.42020
	C	-.100571*	.016714	.000	-.14323	-.05791
C	E	-.362286*	.016714	.000	-.40494	-.31963
	M	.100571*	.016714	.000	.05791	.14323

*. The mean difference is significant at the 0.05 level.

Appendix 3.7 shows comparison of mean area under ROC curves from all observers, according to depth of caries. (AUC_Export = directly exported images, AUC_Med = images captured from a medical-grade display, AUC_Com = images captured from a common display)

Group Statistics

	AUC_Depth	N	Mean	Std. Deviation	Std. Error Mean	Sig. (2-tailed)
AUC _Export	Enamel caries	7	.83386	.058062	.021945	.004
	Dentinal caries	7	.92686	.038120	.014408	
AUC _Med	Enamel caries	7	.49443	.020090	.007593	.045
	Dentinal caries	7	.46400	.029771	.011253	
AUC _Com	Enamel caries	7	.52129	.019405	.007335	.003
	Dentinal caries	7	.56457	.024371	.009211	

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