Optimal Exposure Time for Diagnosis of Approximal Caries Lesions on Digital X-rays

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ABSTRACT

In digital radiography the image can be enhanced and thereby an incorrect exposed radiograph can appear to have optimal brightness but with limited information and possibility to diagnose e.g. caries.

The primary aim of this study was to determine if different exposure times have an impact on the accuracy in diagnosis of approximal caries lesions in bitewing radiographs using a CMOS system. If so, what the optimal exposure time was.

A total of 40 extracted human teeth were selected and evaluated with a digital CMOS system. The teeth were exposed with different exposure times. CBCT was used to validate the presence and degree of approximal caries lesions on every individual tooth surface. The radiographs were evaluated by 11 general dentists and 4 specialists in oral and maxillofacial radiology.

The choice of exposure time did affect the diagnostic accuracy. A higher diagnostic accuracy was achieved when a longer exposure time (> 0.1 sec) was used when comparing kappa values and ROC curves among the observers. The radiologists had a higher diagnostic accuracy than the general dentists. A substantial variation in individual diagnostic accuracy between observers was found.

In conclusion; approximal caries was found to be easier to diagnose when the evaluated longer exposure times were used in the studied digital CMOS system. There was some decline in the longest exposures of the time span. However, when selecting optimal exposure time the patient's age and size should also be taken into consideration.

INTRODUCTION

Radiography has been used in the field of dentistry since the beginning of the 20th century and is an established method to diagnose caries. Especially when diagnosing approximal caries where visual access usually is restricted, radiography has been proven to be a good aid (Young and Featherstone, 2005; Hopcraft and Morgan, 2005; Newman *et al.*, 2009).

Digital radiography has become common during the last decade in the general dental practice. The increased use of digital radiography is due to the lower dose of radiation required to accurately evaluate and diagnose dental pathology. The shorter time span between exposure and display of the radiograph compared to analogue radiography is another benefit. The mean exposure time reduction for digital radiography is 55% compared to analogue radiography. When subjective image quality was compared with analogue radiographs in a study, a majority of the dentists answered that digital image quality was the same as analogue radiographs or even better (Wenzel and Møystad, 2001). Another positive consequence when using digital radiography is the absence of chemicals that are used when developing analogue radiographs (Wenzel, 2004), thereby the environmental impact decreases when choosing digital radiography. Further, there is less need of physical space for archiving digital radiographs.

When exposure parameters are adjusted poorly the radiograph either becomes too dark due to overexposure, or too bright due to underexposure. This was more evident when analogue radiographs were used since it was not possible to enhance analogue radiographs by software as in today's digital imaging. There are also differences between type of sensor used, a CCD (Charge-Coupled Device) or a CMOS (Complementary Metal Oxide Semiconductor) sensor. Generally the CCD sensor is more sensitive to overexposure compared to the CMOS sensor. As a consequence, overexposure can lead to a redistribution of the charge on neighbouring pixels with image artifacts (“blooming”) (Bottenberg *et al.*, 2011).

The analogue radiograph is permanent and cannot be enhanced and if the practitioner cannot make a judgement due to over- or underexposure, another film has to be exposed and further radiation is thereby distributed to the patient.

Clinicians always strive to follow the ALADA philosophy (as low as diagnostically acceptable) (Bushberg, 2014) when using radiography for diagnostics. The digital systems allow clinicians to follow this philosophy further. The software is able to enhance radiographs to an extent where the clinician might not need to do retakes due to over- or underexposure. The radiographic image is automatically getting processed by the software and before it is displayed on the screen, optimization has been made by the computer. The software will try to compensate for over- or underexposure, and normalize the radiograph by adjusting contrast, and brightness.

The raw data in a radiograph exposed with inadequate exposure parameters, will not be optimal, the noise increases the non-useful information in the radiographic image. Radiographic noise can be described as unwanted variations within an image leading to loss of detail in the image (Hayakawa *et al.*, 1996). This noise will affect the practitioner's judgment when *i.e.* looking for caries lesions.

The primary aim of this study was to determine if different exposure times have an impact on the accuracy in diagnosis of approximal caries lesions in bitewing radiographs using a CMOS system. If so, what the optimal exposure time or time span was.

MATERIALS & METHODS

Material

The material comprised of 40 extracted human teeth, all premolars. Only one tooth had a restoration. To identify caries lesions on approximal surfaces, visual inspection preceded a scan in a Computed Cone Beam Tomograph (CBCT).

When the teeth were chosen the aim was to select an equal distribution of teeth with sound and/or carious (white/brownish discolorations, sometimes with cavitation) approximal surfaces to be scanned in the CBCT.

CBCT examination

The CBCT used was a Morita 3D Accuitomo XYZ Slice View Tomograph model MCT-1 (J. Morita Mfg. Corp., Kyoto, Japan).

CBCT examinations were chosen as the gold standard to diagnose approximal caries lesions. Every tooth was placed in a block of clay and scanned individually to minimize artifacts from other teeth and to achieve as good image quality as possible (Figure 1D). Every tooth was scanned for 30.8 sec with slice thickness 0.240 mm, using the high resolution setting (Figure 1). The voltage and electric current were set to 80 kV and 8 mA respectively.

Every CBCT scan was examined by both authors of this article, one undergraduate student in dentistry and one dentist specialized in oral and maxillofacial radiology. A consensus was made for every approximal surface according to a 5-point scale.

Caries scale

The scale used when diagnosing caries and evaluating the degree of the caries lesion was a standardized scale ranging from 0 to 4 (Figure 2A).
0 = the surface was sound.
1 = the caries lesion was localized to the outer half of the enamel.
2 = the caries lesion had progressed into the inner half of the enamel and not crossing the dentino-enamel junction.
3 = the caries lesion had progressed into the outer half of the dentin.
4 = the caries lesion had progressed into the inner half of the dentin.

Bitewing

The dental x-ray unit used was a Focus 50720 (GE Healthcare, Tuusula, Finland). The sensor used was a Schick CDR Elite (Schick Technologies, Long

Island City, NY, USA), which is based on CMOS technology.

Bitewing examinations were performed with teeth mounted in ten clay blocks. One block consisted of four teeth placed in a line with the approximal surfaces in contact with each other, simulating a patient's dental arch (Figure 2B, C, D and E). The clay block was supported by a gypsum holder. The clay surrounded the roots and the upper border of the clay was just below the level of the cementoenamel junction on the teeth, resembling the marginal bone. The sensor was placed in putty silicone impression material, in the same gypsum holder as the teeth (Figure 2E). An acrylic block measuring 19 mm in thickness and equivalent to soft tissue attenuation, was placed in front of the teeth to simulate the cheek. The distance between the sensor and the x-ray tube was standardized to 36 mm.

All ten blocks were exposed using 60 kV and 7 mA. The exposure times selected for analysis were 0.04, 0.05, 0.063, 0.08, 0.1, 0.125, 0.16, 0.2, 0.25, 0.32, 0.4 and 0.5 sec.

Observers

25 observers were asked to diagnose the radiographs during a six-week period, where the only observer requirement was to be a general dentist. 15 of the 25 observers completed the entire task.

Evaluation and Questionnaire

20 radiographs (two different exposures/block) were evaluated per week using the Schick CDR DICOM (Student CDR) system. The radiographs were placed in a randomized order to reduce the risk of bias (e.g. remembering caries lesions from one image to another) when diagnosing. All observers were asked to diagnose caries using the standardized scale described earlier. They were allowed to adjust brightness, contrast and/or any other function available in the Schick CDR software. They were asked to report what monitor model they used when diagnosing the teeth and also requested to use the same monitor throughout the whole study.

The observers received a questionnaire regarding their clinical experience and methods concerning radiographical habits (see appendix).

Literature search

Pubmed and Google Scholar were the databases used for searching and collecting references for the study. Multiple combinations of the following keywords were used: analog radiography, cbct, caries, dental, dentistry, digital dental radiography, diagnostic accuracy, digital x-ray radiography, exposure time, monitor and noise.

References from selected articles were also used.

Statistical methods

The data from our observers was stored in an excel file. IBM SPSS Statistics (v22.0.0) and RStudio (v0.98.501) were used for statistical analysis and visualization.

Cohen's kappa coefficient was used to measure agreement between gold standard and observer (Cohen, 1960). The method takes agreement occurring by chance into account. Kappa values were calculated for every exposure time and agreement between each observer and the gold standard determined by the CBCT examination. From these values, boxplots were made.

Two sets of kappa values were calculated. The first set was based on the original data. The second one was weighted by determining all caries lesions located in the outer half of the enamel (1) as being sound surfaces (0). From each set of kappa values, two box plots were generated (Figure 3), one to show the difference in individual diagnostic performance among the observers and the second to present kappa values (diagnostic accuracy) sorted by exposure times.

In addition, an interpretation of the obtained values of kappa was made, dividing the exposure times in two groups (≤ 0.1 sec and > 0.1 sec) based on their diagnostic performance (kappa values). From these two groups six ROC curves were made (Figure 4).

ROC curves are made to illustrate the sensitivity and specificity for the observers' ability to diagnose caries. An area under the curve (AUC) equal to one corresponds to a perfect test whereas an AUC that is equal to 0.5 or less corresponds to a random guess or worse (Metz 1978).

The six presented ROC curves visualize the differences in diagnostic accuracy between the two groups of observers, the two groups of exposure times and the different degrees of caries lesions.

Ethics

The radiographic exposures were performed under controlled circumstances, meaning that nobody was exposed to harmful radiation. "The Swedish Act on Biobanks" ("Biobankslagen") states that a sample (in this case human teeth) requires consent from the donor if the sample is to be used in research. The act is not applicable in this study since the teeth can't be traced back to the donors.

The Ethics Forum at the Department of Odontology found that appropriate ethics considerations had been made in this degree project.

RESULTS

The diagnostic accuracy at different exposure times was compared. The results indicated that longer exposure times resulted in both higher values of kappa (Figure 3C and D) and values of AUC in the ROC curves. An interval with higher kappa values was found between the exposure times 0.125 sec and 0.5 sec, since the values for the non-weighted kappa values were notably higher for exposure times exceeding 0.1 sec. The weighted kappa values also showed higher scores than the non-weighted kappa values. The kappa values ranged from -0.051 to 0.481 and the weighted kappa values ranged from -0.026 to 0.62.

The ROC curves displayed that specialists in radiology scored a higher AUC than the general dentists did in the majority of caries lesions and exposure times. The AUC showed lower values for lesions in the outer enamel. The AUC was fairly similar when comparing the caries lesions extending into the inner enamel and outer dentin. Though caries lesions extending into the inner enamel showed slightly higher AUC than lesions that had progressed into the outer dentin.

Observer 10 was excluded since the kappa values were much lower compared to the other observers, which may indicate that this observer had misunderstood the task.

Participants and Questionnaire

Of the 25 observers who were asked to participate, 3 observers declined to participate and 7 observers dropped out. Of the remaining fifteen observers who participated in this study, 11 were general dentists (including two dentists in other specialities than radiology) and 4 were specialists in oral and maxillofacial radiology. They had been practising dentistry for 9 months to 35 years with a mean experience of 21.4 years.

Eleven observers answered that they regularly dim their lighting while evaluating radiographs. One observer had no formal education in digital x-ray diagnostics. Two observers used medical grade monitors. Four observers used additional lighting dampening such as window blinds. Ten observers used utilities in the Schick software to alter the radiographs, the most frequently used was contrast/brightness (window/level in Schick software), flashlight and revealer.

All but one observer adjusted the exposure time according to the patient's size, and four observers did not adjust the voltage depending on the type of radiograph (bitewing or apical).

DISCUSSION

Our null hypothesis was that there is no difference in accuracy in caries diagnosis between different exposure times and no difference in diagnostic performance between observers. Also, that the degree of a caries lesion does not affect the detection of the lesion. This was disproven in our study.

The results of the present study showed that caries was easier to diagnose in radiographs that had longer exposure times in the evaluated time span. A time interval for the radiographs that resulted in higher diagnostic accuracy was obtained since the observers didn't perform exceptionally better at one single exposure time, when diagnosing caries. Previous studies made with storage phosphor-plates support this finding (Önem *et al.*, 2012, Svanæs *et al.*, 2000).

Our study indicates that there is a greater chance to detect approximal caries lesions while using the evaluated longer exposure times. This is in agreement with the ALADA principle since, in the long run, it is a justifiable decision as this results in better diagnostics and less retakes due to underexposure. The patient will also acquire earlier prophylactic intervention and avoid invasive treatment.

Questionnaires

Only two observers reported that they used medical diagnostic monitors during assessment of the radiographs and they both scored kappa values above average. However, the number was too small to draw any conclusions on whether the monitor's quality influenced caries diagnostics. The general opinion is that medical grade monitors, often used by radiologists, are more optimal in diagnostics than less advanced monitors. This has been shown not to be the case (Isidor *et al.*, 2009). However, monitor calibration is of great importance to achieve similar results, independent on quality of monitors (Yoshimura *et al.*, 2011). To avoid any influence due to quality or calibration of monitor, it would have been optimal if all the observers had used the same model and type of monitor.

Eleven observers reported that they regularly dimmed the light while diagnosing the radiographs. This is a factor proven to be important while diagnosing caries lesions, especially when the caries lesion has progressed into the dentin (Hellén-Halme *et al.*, 2008; Hellén-Halme and Lith, 2012). We did not include a question if the light was actually dimmed during assessment of the radiographs in this study, and therefore no comparison of diagnostics performance on group level was performed.

Gold standard

In our study, CBCT was chosen as the gold standard to validate the caries lesions. Usually histologic validation is chosen as the gold standard when validating caries lesions, as it has been shown to fulfil the criteria for a robust gold standard (Wenzel *et al.*, 1999). In our study we did not have the resources to conduct histologic validations of the teeth, which is why CBCT was chosen as gold standard.

The amount of teeth with restorations, especially metallic restorations, was minimized to one tooth. Restorations lead to artifacts when scanned in a CBCT, which may in turn lead to misinterpretations when diagnosing caries (Cheng *et al.*, 2011).

CBCT has been shown to be better than analogue digital radiography in determining the degree of small approximal caries lesions (Figure 1) in non-restored dentitions (Akdeniz *et al.*, 2005). Therefore it was chosen as the gold standard for diagnosing caries. Other studies on the other hand indicate that CBCT does not show better diagnostic accuracy compared to analogue radiography, especially when the caries lesions are confined to the enamel (Young *et al.*, 2009). In all these studies, though, the teeth diagnosed with the CBCT have been mounted in blocks with several teeth, and not individually as in our study. Artifacts from adjacent teeth most probably influenced their results.

Agreement

Longer exposure times resulted in higher kappa values, *i.e.* better caries diagnostics.

The kappa values were rather low, at best 0.62 (weighted) (0.49 non-weighted), which corresponds to substantial agreement, but the most frequent values were in the range of 0.21-0.4, which correspond to fair agreement (Viera and Garrett, 2005). One explanation to the low kappa values is that all interpretations from all radiographs were included and some of the radiographs were too bright to interpret and therefore the observers scored worse on them. Another might be that the most frequent caries lesions in this study were lesions extending into the outer half of the enamel. These lesions have been shown to be hard to diagnose correctly (Hintze *et al.*, 1994). Therefore we produced a weighted kappa value which meant that all the caries lesions extending into the outer half of the enamel (1) were made equivalent to not having any caries lesion (0), both for the answers of the observers and the gold standard. This resulted in slightly higher kappa values.

In the boxplot illustrating the weighted kappa values (Figure 3D) the result of diagnosing caries has improved for 0.1 sec and a decline in diagnostics is seen for exposures $\geq$ 0.4 sec. This indicates that detection of caries decreases with overexposure $\geq$ 0.4 sec. If the ROC curves had been calculated using weighted kappa values with exposures 0.1-0.32 sec the values for sensitivity and specificity would probably have been higher.

The ROC curves were calculated with a cut-off at > 0.1 sec using the kappa values in the boxplot with the non-weighted kappa values (Figure 3C) that included caries in the outer half of the enamel. The decline in diagnostics was not as evident for the longer exposures, which is why results from both 0.4 sec and 0.5 sec were included in the ROC curves. It could however be argued that 0.5 sec should have been excluded, using an interval of 0.125-0.4 sec as optimal exposure times.

As seen in the box plot (Figure 3A and B) the kappa values varied a lot between the observers. There might have been several factors that affected the outcome such as experience (Hellén-Halme and Petersson, 2010), lighting conditions and/or further education involving digital radiography.

Distribution of caries lesions

There were 47 sound enamel surfaces, 15 caries lesions extending into the outer half of the enamel, 12 that had progressed into the inner half of the enamel, 6 into the outer half of the dentin and 0 into the inner half of the dentin. Three teeth had occlusal caries that had progressed into the outer half of the dentin.

Most of the caries lesions were confined to the enamel, explained by the fact that the majority of teeth were extracted because of orthodontic reasons and originated from young patients with low caries/restoration rate. The fact that caries lesions confined to the enamel is difficult to diagnose correctly (Hintze *et al.*, 1994) might have had an impact on the results, mainly resulting in lower kappa values and lower AUC in the ROC curves. It would have been better to have more lesions extending into the dentin since these are somewhat more clinically important when determining whether invasive treatment should be performed or not. On the other hand, the enamel lesions are harder to detect which means that the differences in the quality of the radiograph that the different exposure times lead to, are more important since these lesions are very subtle. It is especially important since there usually is an over-/underestimation of the caries lesion compared to the true lesion depth (Jacobsen *et al.*, 2004).

We have shown that differences in diagnostic performance among observers exist and also depending on the degree of caries lesions using ROC curves. Because there was only 6 caries lesions extending into dentin, most of them were early dentin caries lesions which may explain why the ROC curve for caries extending into the inner half of the enamel (grade 2) had a higher AUC than caries extending into the dentin (grade 3). This is usually not the case, lesions that have progressed into dentin normally result in higher diagnostic accuracy than lesions confined to the enamel (Okano *et al.*, 1987).

A couple observers reported that they noticed root surface caries. This was registered as if they hadn't seen any approximal caries since root caries was not to be evaluated in this study. Instructions that root surface caries should not be registered should have been stated more clearly, since some observers might have registered these lesions as caries and incorrect registrations lead to a less accurate result.

ROC curves

The ROC curves illustrate diagnostic accuracy for dentomaxillofacial (DMF) radiologists and dentists for different degrees of caries lesions. DMF radiologists showed slightly higher sensitivity and specificity than the general dentists, this could be explained by a higher level of education and experience (Hellén-Halme and Petersson, 2010) and has also been shown in other studies (Syriopoulos *et al.*, 2000). Further, the general practitioners have to perform the excavation and restoration as result of their diagnosis, and in order to reach high specificity, they might underestimate the lesions to a higher degree. This is in accordance with figure 4C and D where a notch can be seen in the lower left corner. This can be explained by the fact that the scale is composed of several categories and that the observers have underestimated or missed the caries lesions in the inner half of the enamel.

In all diagnostic methods, a combined high sensitivity and specificity is optimal. If that is not achievable, the importance of high sensitivity compared to high specificity in diagnostic tests differs depending on the severity of missed disease compared to treating healthy.
Caries can progress if missed, but invasive treatment of sound teeth should be avoided. Therefore high specificity is important in a population with low caries prevalence.

Considerations

Several circumstances differed between diagnosing caries in our study compared to everyday practice. First, the availability of additional radiographs with different projections of the same teeth exposed at the same occasion. Second, there were no records and earlier radiographs exposed at different occasions over a longer period of time that could have contributed to evaluate the progression of the lesion. Finally, it was not possible to perform a clinical examination of a patient. It is easier to interpret radiographs if the clinician has access to more information.

The diagnostic accuracy in this study does not measure root surface caries, but as seen in figure 2D, the root surface suffers a great amount of burnout (overexposure of the lateral portion of the cervical part of the root, between the cementoenamel junction and the alveolar ridge) due to high exposure time, leading to possible masking of root surface caries (White and Pharoah, 2008).

Seven observers did not diagnose all radiographs, which led to dropouts of observers. These observers reported a lack of time as a major reason. This is understandable since many observers did not have additional time to everyday work for contribution to our study. This fact could also have contributed to stress among the participating observers during diagnosis of caries, which could have affected the kappa value results.

Conclusion

In conclusion, our main finding was that approximal caries was easier to diagnose when a longer exposure time (> 0.1 sec) was used in the studied digital CMOS system. An improvement of caries diagnosing performance was seen with longer exposure times, but with some decline in the longest exposures of the time span. However, the patient's age and size should also be taken into consideration when selecting optimal exposure times.

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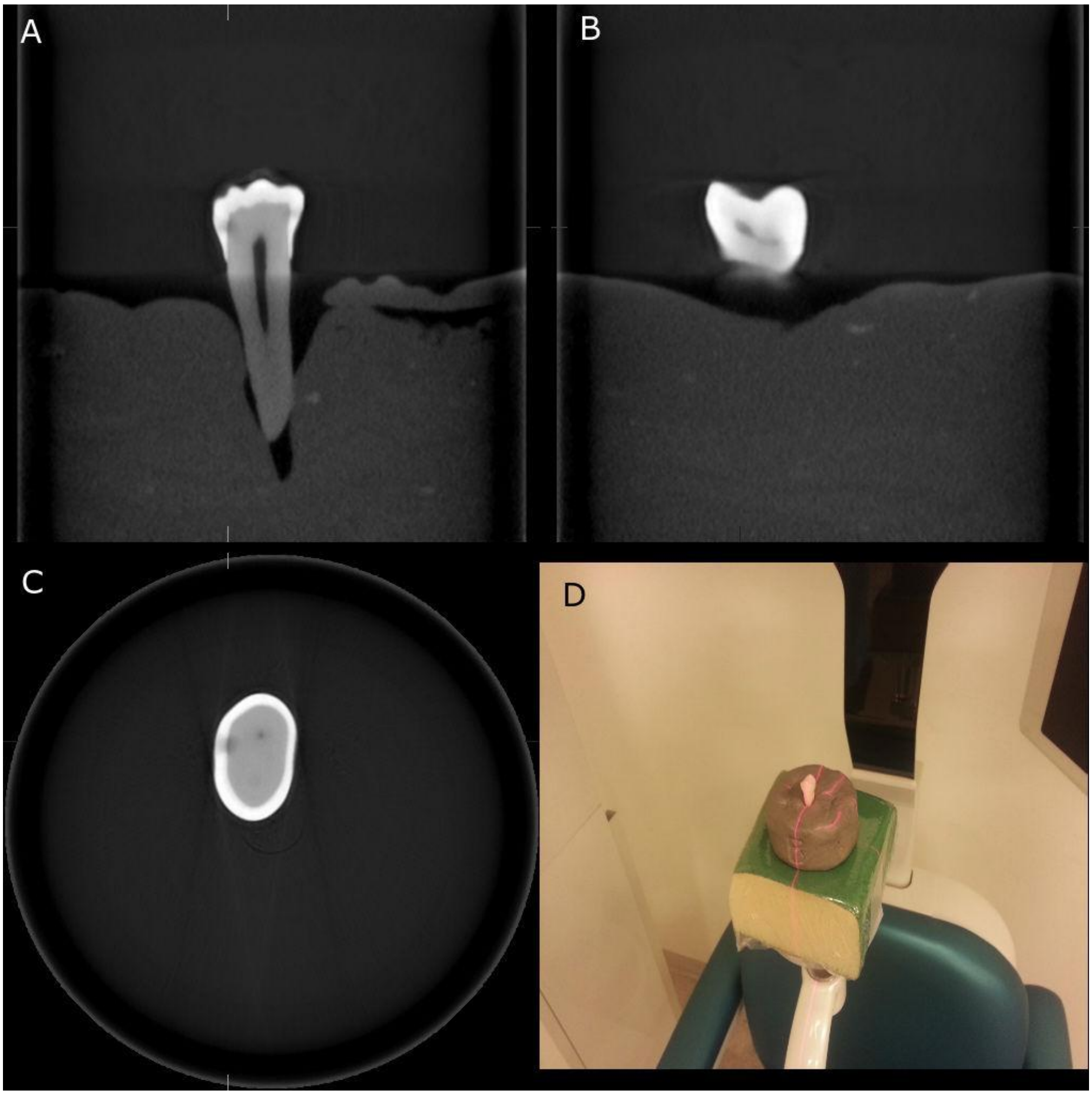

Figure 1. A. Frontal view of the tooth in a CBCT reconstruction (slice) showing carious lesions (left and right side in view A) that have progressed into the outer half of the dentin from three different views. **B.** Sagittal view, **C.** Vertical view. **D.** Tooth mounted individually in clay and scanned in the CBCT.

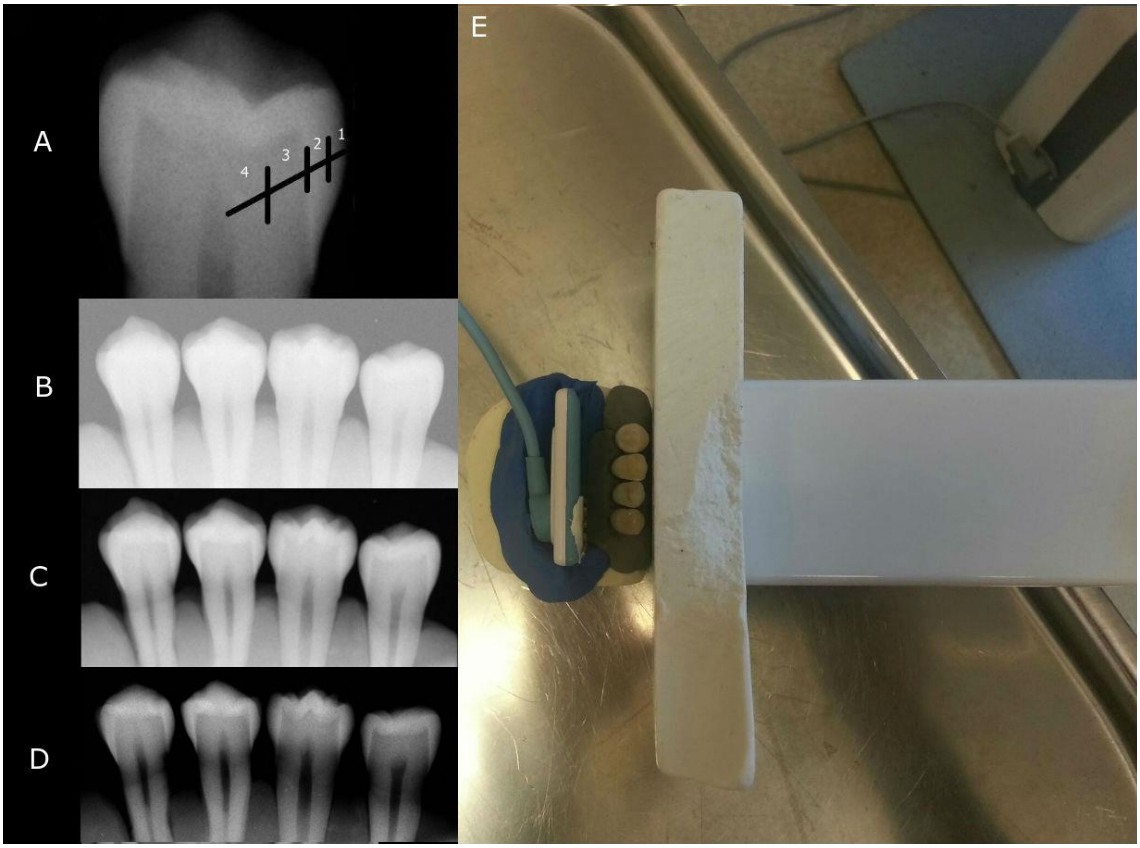

Figure 2. A. Radiograph illustrating the scale used for diagnosing caries.
B, **C and D**. Example of a bitewing projection of the teeth that the observers were asked to assess with an exposure time of 0.04 sec (B), 0.125 sec (C) and 0.5 sec (D). **E.** Teeth mounted in a row in clay to simulate a dental arch with an acrylic block corresponding to the attenuation of the patient’s cheek, all to enable different exposures of bitewing radiographs. The sensor was placed in a putty silicone material.

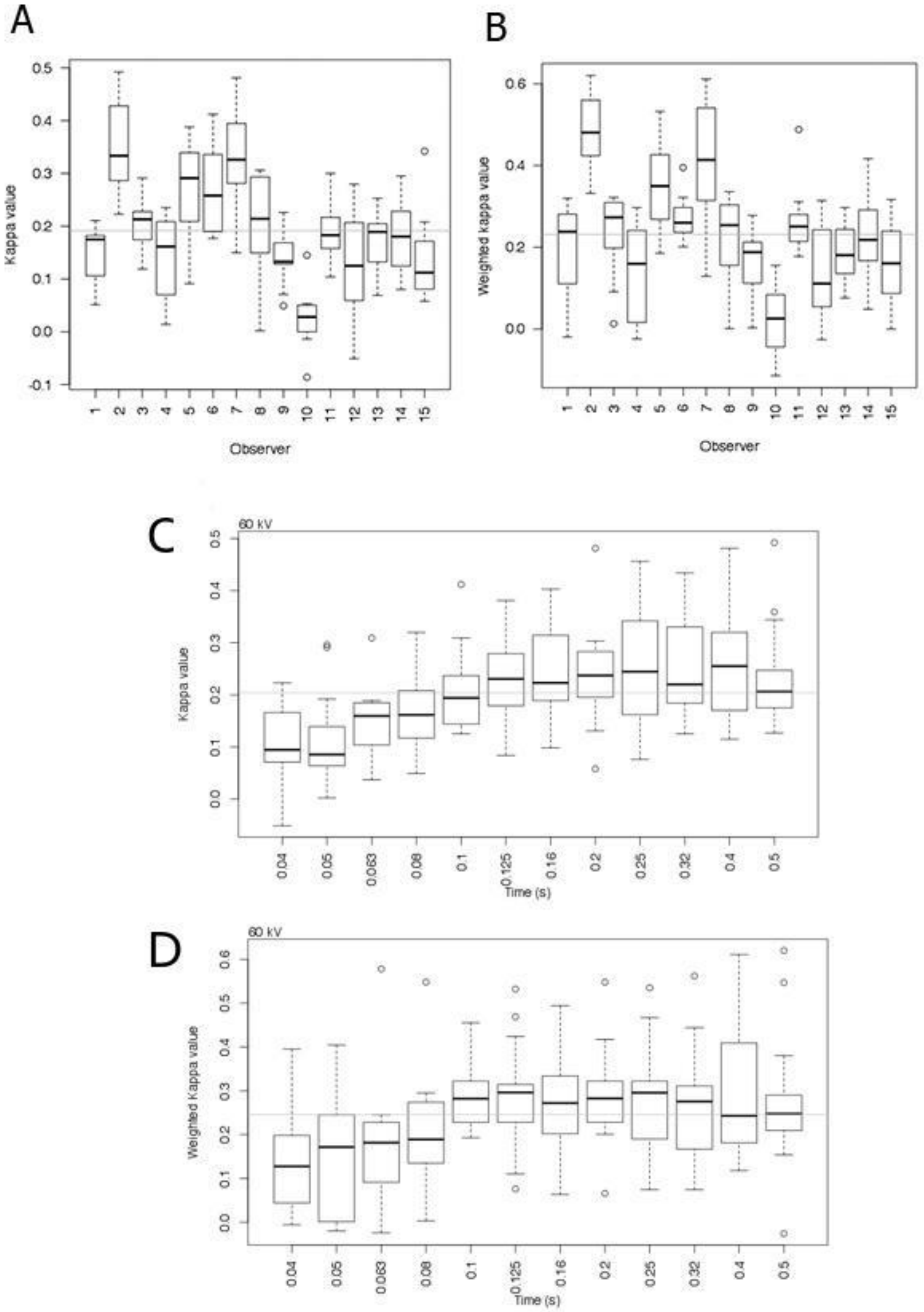

Figure 3. A. Boxplot depicting kappa values for the observer performance (note: in this boxplot observer 10 is included, which is not the case in the other boxplots and ROC curves) **B.** Boxplot depicting weighted kappa values for the observer performance (note: in this boxplot observer 10 is included, which is not the case in the other boxplots and ROC curves) **C.** Boxplot showing the kappa values for different exposure times at 60 kV. **D.** Boxplot showing the weighted kappa values for different exposure times at 60 kV.

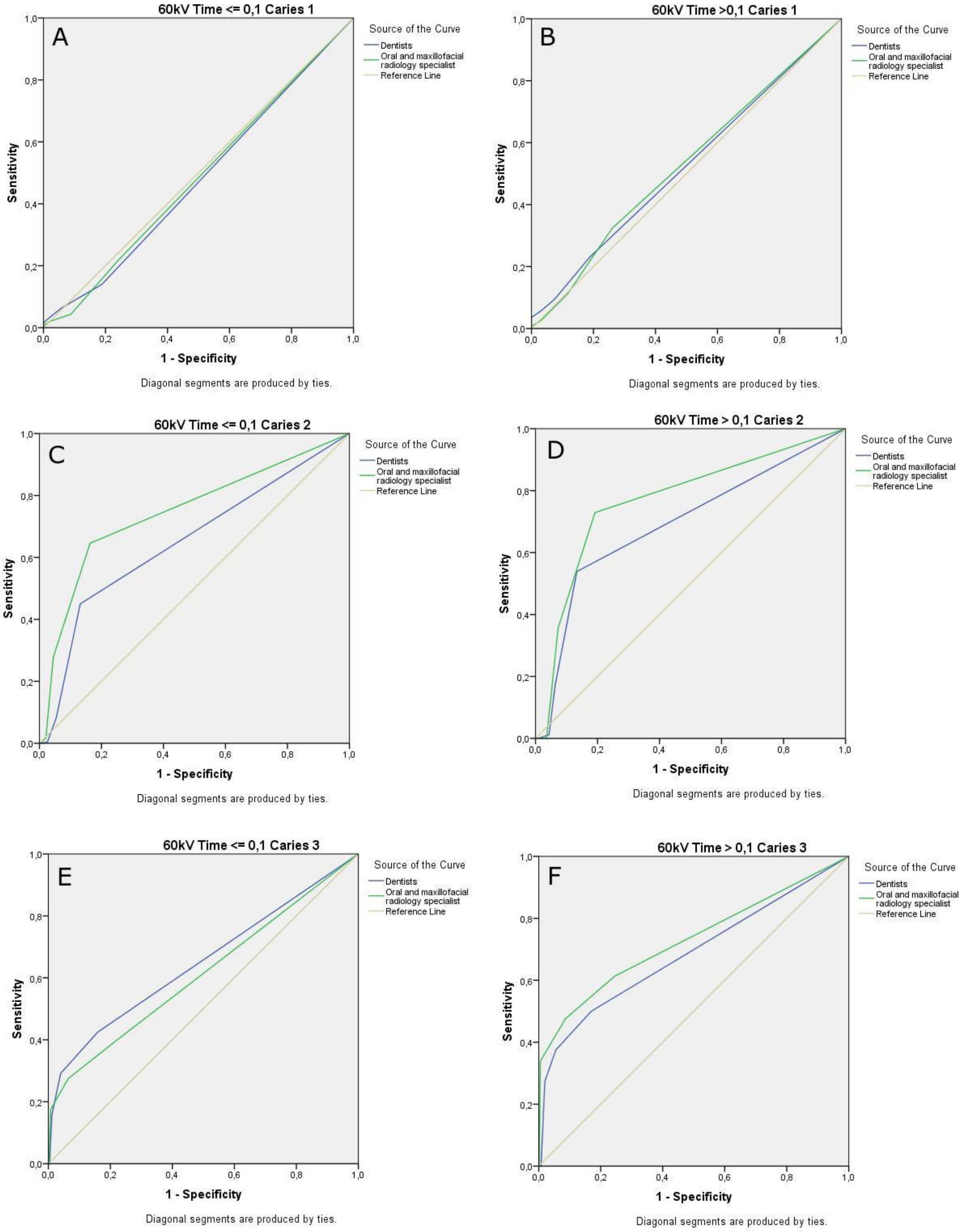

Figure 4. A. and B. ROC curve depicting general dentists' and specialists' assessment of caries that was localized to the outer half of the enamel when the exposure time was equal to or less than 0.1 sec (**A**) and more than 0.1 sec

(**B**). The AUC for the general dentists was 0.478 (≤ 0.1 sec) and 0.523 (> 0.1 sec). The AUC for the specialists was 0.484 (≤ 0.1 sec) and 0.527 (> 0.1 sec).

C. and D. ROC curve depicting general dentists' and specialists' assessment of caries that had progressed into the inner half of the enamel but not crossing the dentino-enamel junction when the exposure time was equal to or less than 0.1 sec (**C**) and more than 0.1 sec (**D**). The AUC for the general dentists was 0.651 (≤ 0.1 sec) and 0.694 (> 0.1 sec). The AUC for the specialists was 0.747 (≤ 0.1 sec) and 0.770 (> 0.1 sec).

E. and F. ROC curve depicting general dentists' and specialists' assessment of caries that had progressed into the outer half of the dentin when the exposure time was equal to or less than 0.1 sec (**E**) and more than 0.1 sec (**F**). The AUC for the general dentists was 0.649 (≤ 0.1 sec) and 0.686 (> 0.1 sec). The AUC for the specialists was 0.611 (≤ 0.1 sec) and 0.729 (> 0.1 sec).

Appendix

Frågeformulär till granskare i undersökning av exponeringsparametrars påverkan på kariesdiagnostik.

(Skicka ditt svar i separat kuvert)

1. Hur länge har du arbetat som tandläkare?

   ____

2. Brukar du dämpa belysningen vid granskning av röntgenbilder?

   ☐ Nej ☐ Ja

3. Vilken skärm använder du vid granskningen (Ange märke och modell)

   ____

4. Använder du annat hjälpmedel för att skärma av ljus vid granskning av röntgenbilder?

   Om ja, vad?

   ☐ Nej ☐ Ja,______________________

5. Har du någon utbildning i digitalröntgen (ex. i grundutbildningen eller externa kurser)?

   ☐ Nej ☐ Ja,______________________

6. Använder du regelbundet bildbehandling eller verktyg vid granskning av digitala röntgenbilderna?

   Om ja, vilken/vilka funktioner?

   ☐ Nej ☐ Ja,______________________

7. Är du specialist eller disputerad inom odontologi? Om ja, i vilket ämne?

☐ Nej ☐ Ja,______________________

8. Brukar du välja olika exponeringstider beroende på patientens storlek, ålder etc?

Om ja, ge exempel

☐ Nej ☐ Ja,______________________

9. Brukar du välja olika spänning beroende på om du tar bite-wing eller apikalbilder?

☐ Nej ☐ Ja, Bite-wing ________kV, apikalbilder __________kV

10. Om du upplever att en bild blir mörk brukar du då ta om den?

☐ Nej ☐ Ja

11. Om du upplever att en bild blir ljus brukar du då ta om den?

☐ Nej ☐ Ja Eventuell kommentar______________________