RESEARCH

Comparison of psychophysical properties of two intraoral digital sensors on low-contrast perceptibility

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Objectives: The psychophysical properties of a new complementary metal oxide semiconductor-based detector, ProSensor® (Planmeca Oy, Helsinki, Finland), in terms of dose response function and perceptibility curve test were performed and compared with those of a charged couple device-based sensor, Dixi® (Planmeca Oy).

Methods: Dose response functions at 66 kVp for a Dixi and a ProSensor were determined by means of multiple exposures to a homogeneous X-ray field covering the whole exposure range. The entry dose of each exposure was measured and registered. The mean grey level in each image was plotted as function of the corresponding exposures for both digital systems. Radiographs of a test object containing ten holes of increasing depth were obtained throughout the exposure range of the two digital sensors at 66 kVp. 12 observers were asked to register the number of perceptible holes in each radiograph. Based on the mean value of the observers' evaluation, the perceptibility curves were constructed, and the integral value under the perceptibility curves were compared between two intraoral sensors.

Results: The results based on dose response function showed that the ProSensor was more sensitive than the Dixi sensor. Paired *t*-test showed that the minimal perceptible low-contrast details were significantly higher for the ProSensor than for the Dixi sensor ($p < 0.001$). The integrals below the two perceptibility curves were 33.4 and 69.2 for the Dixi and ProSensor, respectively.

Conclusion: Applying the new ProSensor may be beneficial to patients owing to its reduced radiation dose and increased perception for low-contrast details in dentistry.

Dentomaxillofacial Radiology (2013) **42**, 20130249. doi: 10.1259/dmfr.20130249

Cite this article as: Shi X-Q, Benchimol D, Näsström K. Comparison of psychophysical properties of two intraoral digital sensors on low-contrast perceptibility. *Dentomaxillofac Radiol* 2013; **42**: 20130249.

Keywords: digital radiography; intraoral radiograph; digital intraoral detector; perception; CCD; CMOS technique

Introduction

Visibility of anatomy and signs of pathology in a radiograph depend on the contrast that is produced and displayed. The function of all medical imaging procedures is to convert physical contrast into visual contrast. The relationship of the physical contrast to the visual contrast is determined by the contrast sensitivity, which is the characteristic of an imaging system that determines the lowest contrast object that can be visualized. Contrast sensitivity is generally expressed as the lowest physical

contrast that produces the necessary image contrast for visibility. In dental imaging, it is often necessary to visualize objects and structures in the jaw bones and dental hard tissues that have low physical contrast, for example for initial caries detection.

The perceptibility curve (PC) test was introduced by De Belder et al,¹ an approach to evaluate radiographical systems, whereby a psychometric method can be used to establish the minimum perceptible exposure difference at various exposure levels. The height of PC reflects the contrast sensitivity of the system, whereas the width represents the exposure range, such as the latitude. In addition, the optimal exposure for a specific digital sensor or

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Received 10 July 2013; revised 14 October 2013; accepted 22 October 2013

film can be represented at the peak of that curve. An aluminium block containing a series of cylindrical wells of different depths is often used as the test object. Unlike receiver operating-characteristic analysis, which takes into account observers' clinical diagnostic decision making, the PC test evaluates the observer performance to detect a simple object. Therefore, the PC test has been applied to evaluate and compare different digital intraoral systems without consideration of dentists' radiological experience.²⁻⁹ The PC test has also been applied to evaluate the effect of different image enhancement modalities on perception.¹⁰⁻¹³

In dentistry, there is a constant innovation of digital techniques. These digital image receptors may be classified into three types according to the techniques that are used for acquiring images, such as phosphor plate, charged couple device (CCD) and complementary metal oxide semi-conductor (CMOS). Both CCD-based and CMOS-based sensors convert X-ray photons into electronic signals and eventually to digital signals by means of an analogue-digital converter. The difference between the CCD and CMOS techniques lies in how the electronic signal in each pixel is transferred. The CCD sensor often has just one output node for all charged pixels. When the pixels are exposed, signals from the output node are converted into voltage, buffered and leave the chip as an analogue signal. With CMOS technique, every charged pixel is individually converted to voltage. The voltage can then be amplified separately before going off-chip as digital bits.

Recently, a new digital intraoral sensor based on the CMOS technique, ProSensor[®], was introduced to the market by Planmeca Oy (Helsinki, Finland). In the present study, the dose response function of the ProSensor was compared with that of an earlier CCD sensor, Dixi[®] (Planmeca Oy). In addition, the radiographs that were obtained from two different sensors were compared using the PC test.

Materials and methods

Dose response function

Dose response functions for the two detectors were determined by means of exposure to a homogeneous X-ray

field. A Planmeca X-ray unit was used at 66 kVp and 8 mA, with a focus-to-object distance of 25 cm. A number of exposures were obtained to cover the whole exposure range of the Dixi and ProSensor. Exposures were measured with a properly calibrated ionization chamber (Model 10×5-6; Radcal Corporation, Monrovia, CA) and, subsequently, expressed in microcoulomb per kilogram. Five exposures were made at each exposure time, and the mean values of exposures were calculated. All the test images were saved as raw 12 bits data. No image processing algorithm was applied. The mean grey levels within the active area of the two detectors were measured for each exposure time with the Romexis[™] programme (Planmeca Oy).

Test object

For constructing PCs, a 25 × 25 × 10 mm aluminium test object was used in the present study. It covered the total active area of the Dixi and ProSensor. The test object had ten contrast details in the form of round holes with a diameter of 1.8 mm. The depth of the holes ranged from 0.03 to 0.3 mm in steps of 0.03 with a standard deviation of 0.01 mm. The 10 positions of contrast details were randomly chosen from a total of 16 possible positions. Grooves were made between the 16 positions so that each one was defined in the test radiograph by a square frame. The objective of the visible framing was to limit the number of false-positive findings by observers.

Test radiographs for constructing perceptibility curves

In total, 14 exposures were made on the test object, with exposure time ranging from 0.012 to 0.32 s for each sensor from marked underexposure to full saturation. All the test radiographs were exposed with the Planmeca X-ray unit at 66 kVp and 8 mA, with a focus-to-object distance of 25 cm.

When the test radiographs were exposed, the test object was randomly rotated and positioned in one of the four possible orientations (0°, 90°, 180° and 270°) to prevent observers from recognizing the pattern of the test object. The test object and an example of the radiographs obtained with the two digital sensors are shown in Figure 1.

Figure 1 The test object together with example of radiographs exposed with both charged couple device and complementary metal oxide semi-conductor at 66 kVp, 8 mA and 0.125 s. The test object contains ten object details in the form of holes of increasing depth. The 10 holes were randomly placed in 16 possible positions. ProSensor and Dixi are both manufactured by Planmeca Oy, Helsinki, Finland

Viewing

The two sets of test radiographs, including a total number of 28 images, were randomly arranged in one sequence. The radiographs were displayed at the centre of the monitor with a surrounding background of dark grey. The monitor used in the study was pre-adjusted to digital imaging and communications in medicine setting with built-in Barten[®] curve.¹⁴ The resolution was set to 1280 × 1024 pixels with 24 bits colour. The observers were not allowed to adjust the brightness or contrast of the computer screen during viewing. Viewing took place in a room with dimmed light.

12 observers evaluated the radiographs at a viewing distance of about 50 cm. They were asked to view each radiograph for at least 15 s and then register the number of perceptible object details. Results were stored in individual files for each observer. These files were subsequently used for the construction of PCs.

Constructing perceptibility curves

PCs were constructed according to De Belder *et al*,¹ where the reciprocal of the minimum perceptible exposure difference, $[(\Delta \log E)_{\min}]^{-1}$, was plotted as a function of the exposure in a logarithmic scale.

The mean background grey level for an area at the centre of each test radiograph was calculated from the digital image data. Then, the mean grey level within a round area inside each representation of an object detail was calculated. Using the dose response function, the mean value of $\Delta \log E$ for each object detail was calculated from all test radiographs of the two sensors and plotted as a function of the number of perceptible object details.^{5,12} The linear characteristic of $\Delta \log E$ vs object details makes it possible to obtain interpolated values of $(\Delta \log E)_{\min}$ from averaged observer results.⁵ Finally, the reciprocal values of all values of $(\Delta \log E)_{\min}$ were calculated and PCs plotted for the two sets of test radiographs.

Data analyses

The dose response functions of the two detectors were presented with scatter plots. The mean numbers of perceptible object details and their standard deviations were calculated and statistically compared between the two types of detectors using the paired *t*-test. For the PC test, polynomial fit were used to demonstrate the total just perceptible exposure difference over the active exposure range for both sensors. The areas under the PCs were compared between the Dixi and the ProSensor by calculating the integral values.

Results

The dose response functions of the two digital sensors are presented in Figure 2a,b. Figure 2a shows exposures up to 15.9 $\mu\text{C kg}^{-1}$ for ProSensor and 31.8 $\mu\text{C kg}^{-1}$ for Dixi sensor in function with their corresponding grey levels. For a 12-bit image, the mean grey level of the active area reached a plateau at around 400 and 1500 and at an

Figure 2 Dose response function for the two sensors. (a) Wider exposure ranges were applied showing that both sensors reached their saturation at exposures around 10 $\mu\text{C kg}^{-1}$; (b) the linear functions for both sensors for exposures are lower than 10 $\mu\text{C kg}^{-1}$. CCD, charged couple device; CMOS, complementary metal oxide semi-conductor. ProSensor and Dixi are both manufactured by Planmeca Oy, Helsinki, Finland

exposure around 10 $\mu\text{C kg}^{-1}$ for both Dixi and ProSensor. Therefore, the dose response functions were subsequently constructed for an exposure range between 0 $\mu\text{C kg}^{-1}$ and 10 $\mu\text{C kg}^{-1}$ for both sensors (Figure 2b). Within this exposure range, both sensors had linear function between exposure and the grey levels. The dose response function was steeper for the ProSensor, indicating

Figure 3 Mean values of perceptible aluminium test object details as a function of exposure for radiographs obtained using Dixi® (Planmeca Oy, Helsinki, Finland) and ProSensor® (Planmeca Oy)

that with the same exposure difference the new ProSensor sensor presents higher contrast details than the CCD-based Dixi sensor.

The mean number of perceptible object details at different exposures for the Dixi and ProSensor are graphically illustrated in Figure 3. It was noted that for the Dixi sensor, none of the observers could detect any object details for exposures lower than $6.3 \mu\text{C kg}^{-1}$, thus these images were not used for constructing PCs. Paired *t*-test showed that for the ProSensor, the perceptible low-contrast details were significantly higher than those for the Dixi sensor over the entire exposure range, especially at low-exposure levels ($p < 0.001$), except for the exposure at $31.8 \mu\text{C kg}^{-1}$, where the ProSensor had reached its saturation, and the perceptible details were significantly higher for the Dixi sensor ($p < 0.001$). Data on $\Delta\log E$, minimal exposure difference, as a function of the number of perceptible object details for the two types of sensors, is illustrated in Figure 4. The functions were linear for both sensors. Figure 5 shows the PCs of the Dixi and ProSensor representing the total number of minimal perceptible radiological contrast over the whole exposure range. The integrals below the two PCs were 33.4 for the Dixi sensor and 69.2 for the ProSensor. At an exposure level around $10 \mu\text{C kg}^{-1}$, it was noted that both sensors provide comparable minimal perceptible radiation contrast. However, across the majority of the exposure range, the ProSensor demonstrated a considerably higher ability to convert physical contrast into visual contrast in the intraoral radiographs.

Discussion

In the present study, the dose response functions of two digital intraoral sensors from the same manufacturer

were measured and constructed. The two sensors had different slopes when plotted on linear scales (Figure 2b). The slope for the ProSensor was steeper, indicating that it has a greater capacity to record small exposure differences than the earlier Dixi detector. It was somehow unexpected that the Dixi sensor reached to its saturation already around 1500 for a 12-bit data. Since the dose response function in the present study was constructed

Figure 4 Exposure differences, $\Delta\log E$, as a function of the number of object details. ProSensor and Dixi are both manufactured by Planmeca Oy, Helsinki, Finland

using raw images without any kind of image processing algorithm, we then may expect that in clinical situations, a wider range of histogram could be used when a radiograph is image processed. Nevertheless, the present results indicate that the ProSensor has a higher potential than the Dixi sensor to convert radiation contrast into visual contrast.

The dose response function showed no more than the physical properties of the digital sensors. Therefore, the capacity of the two intraoral digital detectors to register low-contrast differences was studied by means of the PC test. PCs for the two types of sensors demonstrated that the integrals of the area under the PC curves for the ProSensor were doubled compared with that of the Dixi sensor. It was also found that the exposure range, where the contrast details could be perceived by the observers, was clearly narrower for the earlier Dixi sensor than for the ProSensor (Figure 5). Both detectors showed low perception at low exposures and at extremely high exposures, implying that the human visual system was relatively insensitive to contrasts in the very dark and light regions. Across the middle exposure range, at exposure around $10 \mu\text{C kg}^{-1}$, the minimal perceptible exposure difference was comparable between the two sensors. However, this range is too limited for the Dixi sensor.

The PC test includes observers' viewing; therefore, it is a very useful complement to those physical parameters of radiographic systems. However, it is still a laboratory test on detection of object details with simple patterns using an aluminium test object. It may therefore not be applied rigidly to a clinical situation because diagnosis involves the interpretation of more complicated radiographical signs.¹⁵ Nevertheless, based on our results, it may be expected that the diagnosis, for example on caries detection, may be improved for the clinician by changing from the previous to the new generation of intraoral sensor. Further clinical studies involving diagnostic tasks need to be performed in the future to verify the expected improvement.

Caution needs to be taken when comparing the PCs between different studies. The areas under the PCs not only depend on the physical properties of a radiographical system but also on the size of the object details of the test object and the applied image-processing algorithm. Recent intraoral digital techniques usually apply a pre-processing algorithm or a combination of algorithms automatically to each image directly after exposure to display each digital X-ray with optimal light intensity and contrast. The algorithms among different systems may differ. To focus on the comparison of the two types of digital sensors, raw images were applied in the present study to exclude the effect from image

Figure 5 Perceptibility curves for radiographs exposed with Dixi[®] (Planmeca Oy, Helsinki, Finland) and ProSensor[®] (Planmeca Oy)

processing algorithms. It may be expected that the area under the PCs would be dramatically improved when the pre-processing and the post-processing algorithms were available in a clinical situation.

Conclusion

The present study showed that the ProSensor was more sensitive and had a wider exposure range than the Dixi sensor. Significantly more object details could be detected

with the ProSensor than with the Dixi sensor for the entire exposure range except for exposure at $31.8 \mu\text{C kg}^{-1}$. These findings imply that applying the new ProSensor may be beneficial to patients owing to its reduced radiation dose and increased perception for low-contrast details in dentistry.

Acknowledgments

The authors would like to express their sincere thanks to the observers who participated in the evaluation of radiographs.

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