RESEARCH ARTICLE

The effect of anatomical noise on perception of low contrast in intra-oral radiographs: an *in vitro* study

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Objectives: Radiographic images suffer from varying amounts of noise. The most studied and discussed of these is random noise. However, recent research has shown that the projected anatomy contributes substantially to noise, especially when detecting low-contrast objects in the images. Our aim, therefore, was to evaluate the extent to which overprojected anatomical noise affects the detection of low-contrast objects in intra-oral images.

Methods: Our study used four common sensor models. With each sensor, we took four series of images, three series with and one series without an anatomical phantom present. In each series, we exposed a low-contrast phantom at 18 different exposure times using a standardized method. 4 observers evaluated all 288 images.

Results: The low-contrast characteristics differed substantially when imaging low contrast on a homogeneous background compared with imaging low contrast when an anatomical phantom was present. For three of the sensors, optimal exposure times for low-contrast imaging were found, while the fourth sensor displayed a completely different behaviour.

Conclusions: Calibrating the low-contrast properties of an imaging system using low-contrast objects on a homogeneous background is not recommended. On an anatomical background, low-contrast properties are completely different, and these will mimic the clinical situation much more closely, directing the operator how to best use the system. There is a clear demand for further research on this subject.

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Introduction

Digital radiography in dental care became available about 20 years ago. Since its introduction, researchers have performed many investigations of these techniques. Several previous studies have evaluated the image quality^{1–3} and thereby the diagnostic accuracy for various diagnoses.^{4,5} Studies have concluded that all links in the digital chain must be optimized to maintain a high diagnostic accuracy.⁶

Low-contrast detectability is a key issue in intra-oral X-ray imaging; for example, in the detection of caries. Insuring this detectability is a major task in dentistry.

Quality assurance of low-contrast imaging properties is important but difficult to perform. In medical radiology, these methods have traditionally relied on imaging phantoms containing low-contrast objects on a homogeneous background.⁷ Recently, some have questioned the validity of such methods⁸ and found that they do not actually reflect the low-contrast properties of an imaging system in a clinical situation.⁹

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Table 1 Technical parameters for the sensors used in the study

Manufacturer	Product	Type	Size (mm)	Active area (mm)	Matrix size (pixel)	Pixel size (µm)	Bit depth (bit)
Gendex® Dental Systems, Hatfield, PA	Gendex Visualix® eHD	CCD	40.5 × 33.0	34.1 × 27.0	1747 × 1384	19.5	12
Gendex Dental Systems	Gendex GXS 700	CMOS	42.0 × 31.0	36.0 × 25.9	1842 × 1324	19.5	16
Planmeca Oy, Helsinki, Finland	Planmeca ProSensor®	CMOS	44.1 × 30.4	33.8 × 24.6	1196 × 868	28.3	12
Schick by Sirona, Long Island City, NY	Schick 33	CMOS	42.5 × 31.0	36.0 × 25.6	2400 × 1708	15.0	12

CCD, charge-coupled device; CMOS, complementary metal-oxide semiconductor.

Until recently, noise in radiographic images has been considered to consist mainly of random noise in the form of quantum noise (random spatial and temporal variations in the number of photons impinging on the imaged object). Accordingly, the radiation dose was believed to be the most important factor affecting image quality. Recent research, however, has demonstrated

that this is most likely not the case.¹⁰ In recent years, research in breast imaging¹¹ has investigated how low-contrast objects are imaged in radiographs when superimposed on the adjacent tissue. Timberg et al¹² described how to use tomosynthesis to suppress the disturbing anatomical noise. They concluded that the projected anatomy was the dominant source of noise affecting low-contrast lesions >1 mm, both in images produced using the tomosynthesis technique and in two-dimensional imaging. To our knowledge, investigations in dental digital radiography have not yet evaluated the influence of anatomical background noise on low-contrast detectability. Thus, this study evaluated the extent to which anatomical noise affects the detection of low-contrast structures in dental intra-oral images.

Methods and materials

We used four different sensor models from three manufacturers: one charge-coupled device and three complementary metal-oxide semiconductor sensors. Table 1 gives the technical parameters for each sensor.

Phantoms

We employed a low-contrast phantom made of a Plexiglass plate (Figure 1), comprising 15 holes (recessions) distributed in 3 rows of 5 holes each. The depth of the holes decreased across the rows in 1-mm intervals. The holes in the first (leftmost) column were 5-mm deep and in the last (rightmost) column they were 1-mm deep. We milled the holes to obtain a flat bottom surface. The diameter of all holes was 3 mm.

As an anatomical phantom, we used a specimen of the human mandible (>50 years old and not identifiable) with three molars and one premolar (Figure 2).

Irradiation geometry

To simulate the soft tissue, we placed a 20-mm-thick¹³ Plexiglass plate in front of the phantoms. We mounted the sensor, phantoms and soft-tissue equivalent in a custom-designed jig of steel and aluminium (Figure 3) and then exposed the low-contrast phantom both with and without an anatomical phantom placed in front of it. Because the study was carried out in three clinics, we used three different X-ray units:

Figure 1 Low-contrast phantom custom-designed from Plexiglass with 15 holes of varying depth. Each hole has a diameter of 3 mm. The three holes in the first column have a depth of 5 mm, in the second column 4 mm, in the third column 3 mm, in the fourth column 2 mm and in the fifth column 1 mm.

Figure 2 An anatomical phantom comprising a specimen of a human mandible.

- Gendex[®] Expert[®] DC (Gendex Dental Systems, Hatfield, PA) for the Gendex sensors
- Prostyle Intra (Planmeca OY, Helsingfors, Finland) for the Planmeca sensor
- Promax Intra (Planmeca OY, Helsingfors, Finland) for the Schick sensor.

Prior to exposing the sensors, we determined the output (mGy per second), filtration and reproducibility of the X-ray units using a RaySafe ThinX Intra instrument (Unfors RaySafe AB, Billdal, Sweden) placed at the same position as the intra-oral sensors. This test found the output to be the same ($\pm 3\%$), the filtration (measured as the half-value layer) to be the same (± 0.05 mm aluminium) and the reproducibility to be extremely good for all units at all the exposure times used in the study. The deviation in the dose over 10 repeated exposures was negligible at any exposure time in each of the 3 X-ray units. The Gendex X-ray unit had a focal spot size of 0.4 mm while the Planmeca units had focal spot sizes of 0.7 mm. We believe that this difference did not affect the results concerning low-contrast properties of the sensors studied. Exposures used a 65-kV (Gendex) or 66-kV (Planmeca) tube voltage and exposure times ranging from 0.02 to 1.00 s over 18 equal steps. All X-ray units used the same holder, and the distance from the focus to the sensor was 390 mm.

The phantom was imaged in four series. The first series used only the low-contrast phantom while the following three series imaged both the anatomical phantom and low-contrast phantom. In the last three series, we placed the low-contrast phantom in three different positions in relation to the anatomical phantom. This allowed us to expose the same areas of the anatomical phantom with holes of varying depths. In the following, these series are denoted as Series 1, 2 and 3. We positioned the holes of each column, which all had the same size and depth, first in the bone area (inferior to the roots), then in the tooth-substance area (bone and tooth substance) and finally in the crown area. A specific column in the

phantom had holes of the same depth; the leftmost column had the deepest holes and the rightmost column had the shallowest holes, as illustrated in Figure 3.

The images were captured using the software supplied by the vendor of the sensor. Acquisitions used the highest possible resolution with the maximum bit depth for the sensors. We exported the images in either the digital imaging and communications in medicine (Schick and Planmeca) or uncompressed tagged image file format (Gendex). Figures 4a,b show the examples of the images with and without the anatomical phantom.

For intra-observer agreement, 1 series was re-evaluated, in total 270 observations for each observer. The re-evaluations were made more than 3 months after the preceding evaluation. Kappa statistics estimated the intra-observer agreement.¹⁴ Values were interpreted as per Altman's adaptation¹⁵ of the Landis and Koch¹⁶ guidelines.

Observers

Four observers evaluated the images: three specialists in oral and maxillofacial radiology (LO, BS, KHH) and one medical physicist specializing in diagnostic radiology physics (MN). We did not calibrate the observers, since the objects they were evaluating consisted of simple circles (holes in the low-contrast phantom).

Image evaluation

The evaluation used the ImageJ software (National Institute of Health, Bethesda, MD). All computers ran Windows 7 Professional (Microsoft[®], Redmond, WA) as their operating system. The brightness and contrast settings of the monitors were adjusted¹⁷ for optimal display as suggested by the American Association of Physicists in Medicine (AAPM, College Park, MD), using test patterns TG18-CT and TG18-QC.¹⁸ Before

Figure 3 Anatomical and low-contrast phantoms mounted in the jig with the Plexiglass plate in front of the sensor. The arrow indicates the direction of the X-ray beam.

Figure 4 (a) Imaging low-contrast objects on a homogeneous background. The contrast amplifies as the histogram stretches so that the pixels in the contrast objects will occupy a significant part of the greyscales available. The rectangles and squares indicate the part of the image from which the histograms are generated. The circles indicate the different influence on the histograms of the contrast object in the two cases. (b) Imaging low-contrast objects on an anatomical background. The contrast object overlaid on the anatomical background occupies a much smaller part of the histogram, making it much less visible.

evaluation, we adjusted the window levels to display the images with fixed histogram clip levels of 0.35% using the “auto-adjust” command in ImageJ to optimize the greyscale display characteristics.

For images of only low-contrast phantom, we graded the visibility of the holes as “visible” or “not visible.” For images with the anatomical phantom, we graded the visibility of the low-contrast structures using a five-level graded scale: 0 = not visible, 0.25 = just visible, 0.5 = visible, 0.75 = clearly visible and 1 = very clearly visible. For each exposure time, the total score was the sum of the individual scores for all 15 holes.

Results

Figure 5 illustrates the number of visible holes when imaging only the low-contrast phantom. Three of the sensors responded similarly, meaning that all holes in the low-contrast phantom were visible in the images within a limited range of exposure times. At higher exposure times, the three sensors were saturated, and no pixel values could be read. The characteristics of the Gendex GXS 700 sensor (Gendex Dental Systems) differed radically from those of the other three sensors. In the images, all holes in the phantom were visible at almost all exposure times up to at least 1 s.

Figure 6 presents individual observer scores (total scores for each exposure time) and their mean values for the Gendex Visualix® eHD sensor (Gendex Dental Systems) for Series 1, 2 and 3 with the anatomical phantom in place. We present individual observer results for this sensor only, in order to illustrate interobserver variation. For each exposure time, the total score can range from 0 (no holes visible) to 15 (all holes

clearly visible). This sensor clearly has an optimal exposure time.

Figure 7 shows the mean values of the scores for all observers for all four sensors when imaging the anatomical phantom. Interobserver variation appeared similar to the results in Figure 6. Thus, only mean values for the four observers are presented. The characteristics differ from those found (Figure 5) when only imaging the low-contrast phantom. Even at the most optimal exposure time, the observers were unable to distinguish as many holes when the anatomical phantom was present as they could without the phantom. The intra-observer agreements were found to be from moderate to very good, (0.44, 0.77, 0.84 and 0.85). The Planmeca and Schick sensors performed similarly to the Gendex eHD sensor in that they clearly showed an optimal exposure time. The Gendex GXS-700 sensor, however, exhibited completely different characteristics, where above a certain exposure time, it performed equally well.

Discussion

This study provides a more thorough understanding of the concept of anatomical noise in intra-oral radiographs. The methods developed differ from those previously used for studying the low-contrast properties of intra-oral radiographic images. Our method was essentially an *in vitro* setup using a low-contrast hole phantom imaged together with an anatomical, human mandible specimen. This arrangement made it possible to evaluate the degree to which it is possible to visualize a specific low-contrast level in combination with interference from various anatomical structures. The

Figure 5 Varying exposures of the low-contrast phantom on a homogeneous background.

Figure 6 Summed score for all observers on the Gendex Visualix® eHD.

advantage of this method is that it makes it possible to better simulate a real anatomical situation. This topic has not, to our knowledge, been discussed previously in the context of dental radiography. Medical radiology research had thoroughly evaluated the role of anatomical noise in connection with mammography¹² and chest radiography.⁹ New tomographic equipment in medical radiography is under continuous development in order to obtain better diagnostic capabilities by suppressing

overprojected anatomical structures. Such structures appear as anatomical noise that can obscure pathological structures.⁷ There is a clear demand for more research regarding how anatomical noise affects the detectability of low-contrast objects in dental radiography and interest in how the outcome of this research may lead to development of new equipment and methods. A major challenge in such research is that compared with studying only the quantum noise, many more factors will influence the optimization of image quality. This will put much greater demands on the planning of experimental work in order to optimize the image quality than the demands associated with the traditional approach to studying the effects of stochastic noise.

Four observers evaluated the images. At first, this number may appear few. However, although the recorded observations differed slightly, the resulting curves were very similar, which indicates that the results are reliable. The differences in observation were most prominent at the end points of the curves. The observer scale had only five steps, which could be considered rather few, and this may also have affected the results; it was difficult to distinctly demarcate the steps, which could lead to a kind of truncation error. Because the holes were in the same positions in the various series, there could be a tendency in the observers to recognize the pattern in which the holes are oriented. While this might create a small risk of overestimation of the visibility of the holes, it shows that, if anything, our results underestimate the level of anatomical noise. We chose the size and depth of the holes in the phantom to produce similar low-contrast properties as those found for caries and periapical lesions with varying levels of extension. The observers almost never found the holes of shallow depth but, as expected, they frequently found the large holes. This suggests that the phantom did, in fact, adequately reflect the clinical situation. The markedly lower score for Series 3 is explained by the fact that the phantom was positioned so that the shallowest holes were imaged. In Figure 6, it can be noted that the results for Series 1 and 3 differ significantly for Observer 2 and, to some extent, also for Observer 4. This may be explained by the fact that these observers were the most experienced in evaluating digital dental radiographs.

Another source of error that could have altered the reliability of the study was the fact that we used only one sensor of each brand. However, exposures with each sensor were repeated several times, and the readings remained stable.

The results clearly showed that the use of low-contrast objects on a homogeneous background is not representative of the low-contrast properties of the system being investigated. Displaying low-contrast objects on an anatomical background revealed different characteristics of the low-contrast properties for the system. Figures 4a,b illustrate this, showing the histograms for both the homogeneous background and anatomical background. In the homogeneous case, the histogram

Figure 7 Total scores for all sensors.

clearly changes with the presence of the contrast object, whereas for the anatomical background, the effect on the histogram is very small. Also, because human vision easily recognizes objects with familiar shapes—such as circles, squares or triangles—this will favour detection on a homogeneous background.

Using an anatomical phantom also revealed the difference in how the various manufacturer machines handle histogram data and how they differ in low-contrast resolution depending on the exposure time. Therefore, the methodology facilitates finding the lowest possible exposure time that does not sacrifice low-contrast detectability.

In this study, it became obvious that two of the sensors evaluated had a greater dynamic range than the other two. One of the sensors, the Gendex GXS-700, had an extremely wide dynamic range. Employing sensors with very wide exposure latitudes is something that the dental radiology community must discuss thoroughly. From a radiation-protection point of view, this is clearly the wrong way to go. In the hands of an unskilled or ignorant user, it would be tempting to use unnecessarily long exposure times that always guarantee images with good quality and low noise.

Such use will violate the ALARA (as low as reasonably achievable) principle that is fundamental to all radiation-protection efforts in radiology. It is strange and distressing that manufacturers are currently marketing sensors with this behaviour, thereby making radiation-protection work in the oral radiology field more difficult. It should be mandatory for any producer of intra-oral sensors and capture software to design a system that blocks the signal from the sensor above a certain signal level or exposure time. This, if anything, would be an excellent sales argument.

Conclusions

Characterizing the low-contrast properties of an imaging system using low-contrast objects on a homogeneous background is not recommended. On an anatomical background, low-contrast properties will be completely different, and these will mimic the clinical situation much more closely, directing the user how to best use the system. There is a clear demand for further research on this subject.

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