Comparison of image quality between a digital panorama X-ray unit with a CdTe-CMOS detector and panorama X-ray units with other types of digital detectors

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Abstract
An investigation of the image quality of 5 panoramic X-ray units was carried out for this paper. Measurement of the MTF clearly shows good resolution for the Art Plus unit (MTF(50%) = 5.61 lp / mm) compared to the average of all 5 of the units (3.44 ± 1.55 lp / mm). To investigate image noise, the ratio was calculated between average gray scale value and standard deviation in a 32×32 matrix (R_{32x32}). Compared to the other units, identical regions in the image are less noisy for the Art Plus unit (R_{32x32} = 92.28 and R_{32x32} = 19.40 ± 11.00 for the other units). Also image displacement of a series of images was determined for the Art Plus and the Pro Max unit. The displacements were between 1-5 Pixels for both.

1. Introduction

Progress in digital detector development is playing an increasingly important role in the area of dental X-ray methods [1]. In dealing with digital detectors for X-ray radiation, the challenge is to find the most efficient way of transforming X-ray quanta into an electronic signal. In the case of CCD detectors, this is accomplished by a matrix of light sensitive photodiodes. Conventional CCD and CMOS detectors use a fluorescence layer to transform X-rays into visible light. The thicker the fluorescence layer is, the better will be the optical efficiency. However, spatial resolution is reduced due to scattering of light in the fluorescence layer.

One new development is CdTe detector technology. Here, a CdTe layer replaces the fluorescence layer. X-ray quanta release electrically charged particles in this layer, which then flow in an electric field in the direction of a diode matrix. Because there is no transformation into visible light taking place, there is no additional optical scattering. This leads to the higher resolution.

In this article, a comparison between the image quality of a digital panorama X-ray unit with a CdTe detector (ART Plus[1]) and other more standard digital panorama units is presented. Qualitative comparisons and ratings of the image quality of film and digital panorama photos have been performed where experienced observers rate image quality visually [2,3]. In this article, quantitative measurement (modulation transfer function MTF) will be emphasized and image noise and image displacement will be investigated.

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2. Materials and Methods

Creating a test image

Test images were used for comparing image quality. For the sake of practical relevancy, a special anthropomorphic bone phantom was used. This makes possible a qualitative as well as a quantitative evaluation of the X-ray image. The phantom was positioned identically for each of the devices and the tube voltages kept as similar as possible (Tab.1). All the images were stored (8 bit resolution) and analyzed in the same manner. The test images were analyzed with Matlab[2] using the *Image Tool Box*

Tab.1. The devices used and the exposure parameters for the test images

Unit	Tube voltage U / kV	Charge Q / mAs
ART Plus	70	94.5
Sorodex Cranex Novus	70	63
Kodak 9000	70	68
Sirona Orthophos	71	112
Planmeca ProMax	70	96

Determining image resolution

For determination of the modulation transfer function MTF, a sharp and piecewise straight edge of a tooth was used. Tooth enamel is very radio-opaque so the tooth edge functions approximately as a step function. A small exactly defined area identical for all panoramic images was cut out of the X-ray images (Fig.1).

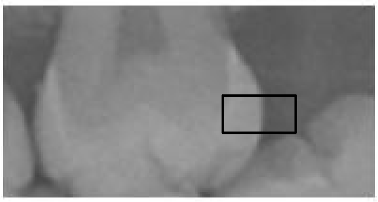

Fig. 1. Area of tooth used for determining the MTF (black frame)

Determining image noise

In an additive model, the image $I(x, y)$ (with image coordinates x and y) is given by the picture information (projection of the object image $P(x, y)$) plus the noise component $N(x, y)$: $I(x, y) = P(x, y) + N(x, y)$. It can be assumed that the pixel values for the noise component will have a statistical distribution around zero. This distribution is characterized by a standard deviation. Olsen [4] compared six methods for estimating the deviation from white noise in real images. Filtering the image information (i.e., separation of image contents) beforehand proved to be

[2] V. 7.5, The Mathworks Inc.

especially advantageous for this. The better filtering methods are being sought that would separate the image noise from the diagnostic content of the image itself as completely as possible [5].

The comparison of the devices in Tab.1 was made using a single image. The standard deviation as well as the variance can be estimated for a region of a real image having a distribution of intensity that should be as homogenous as possible. Local estimates of average intensity and variance can be improved by combining with measurements at other locations [6]. For all the test images, sections without any anatomical structures (analogous to an empty image) were chosen. Of course, structures in the panoramic picture were smeared due to motion blur. For this reason, the chosen areas of the pictures were investigated for systematic features of darkening. In addition, the Fourier transformation was calculated for each area in order to identify possible correlations in the intensity distribution. Several sections of various sizes (128 x 128, 64 x 64 and 32 x 32 – image matrix) of each image were also compared to each other. The following expression was used for quantifying image noise:

$$R_{N\times M} = \frac{1}{s \cdot N \cdot M} \cdot \sum_{n=1}^{N} \sum_{m=1}^{M} I(x_n, y_m) \qquad (1)$$

Here, s is the estimate of the standard deviation σ of the gray scale values (*x* and *y* are the image coordinates). Calculating $R_{N\times M}$ at chosen locations in the image gives only fragmentary insight because the places that show homogenous distribution of intensity can only be found in certain areas of blackening. For this reason, an additional image was taken with a cylindrical water phantom for verification (diameter 20 cm). Such images display an adequately homogenous local intensity distribution. However, due to movements of tube and detector (translation and rotation), regions of varying intensity are formed over the whole picture because the path length of the x-rays through the phantom changes.

Another difficulty is mechanical instability which can lead to shifts in the positions of the structures in the image. These shifts are especially important when they occur during the actual taking of a picture and result in changes to the relative positions of structures within the image. Such shifts were determined for two of the devices being investigated by calculating the difference image $\Delta I(x,y) =$ $\Delta I(x,y) = I_2(x,y) - I_1(x,y)$ of pictures taken in succession.

3. Results

Resolution

Fig. 2 shows the MTF for the ART Plus unit. Various characteristic values can be read from the curve. The MTF(80%) value lies above 3 lp/mm. According to the information given by the manufacturer, the value MTF(>75%) is at 2 lp/mm, which is clearly satisfied here. The MTF(50%) value results in a frequency of 5.61 lp/mm and for MTF(30%), the resulting image frequency is 6.26 lp/mm. For MTF(50%), the average value plus/minus standard deviation is equal to 3.44 ± 1.55 lp/mm for all five devices. For MTF(30%), it is equal to 4.86 ± 1.24 lp/mm. For the ART Plus, the result is above the average value plus standard deviation in both cases.

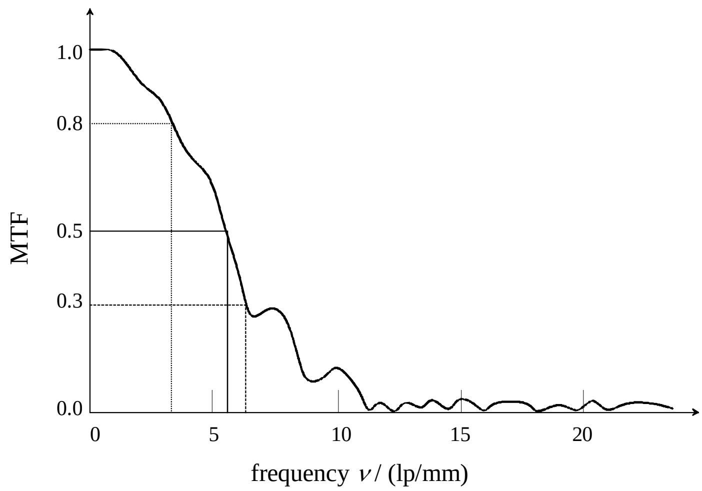

Fig.2. MTF for the ART Plus unit, measured in the section shown in Fig.1.

Image noise

In order to calculate the value $R_{N\times M}$, four image sections (32x32 pixels) were chosen that were identical in every picture of every device. The results scatter enormously (standard deviation of the average value of R_{32x32} is 34.92 ± 33.83). The resulting value for all the units without ART Plus was 19.40 ± 11.00. ART Plus's value (R_{32x32} = 92.28) lies distinctly above all the others. In areas of similar average intensity, the R_{32x32} values for the images made with the water phantom show comparable values (1.25% deviation). As expected, the R_{32x32} values are correlated with the gray scale average.

Image shift

A series of 10 pictures was taken one after another with two devices (Art Plus and Pro Max). Two successive x-ray images were then used to calculate the difference image $\Delta I(x, y)$. Shifts are especially clear to see at the edges. Since only horizontal displacements can be observed in the images, the tooth edge in Fig.1 was very suitable for determining these shifts. Fig.3 shows a cut through the difference image in the *x* direction at the location of the edge. A pattern results that is characteristic to the form of this edge. This pattern can be described by the distribution of difference values with a maximum and a half-width. The shift has been simulated in Fig.4 where we see that maximum and half-width can be assigned to a shift by a certain number of pixels. The half-width is useless for small shifts but the maximum can be used very well. This behavior is reversed for large shifts. Both units showed the greatest shift (and consequently, the highest value for the maximum) between the first and second pictures.

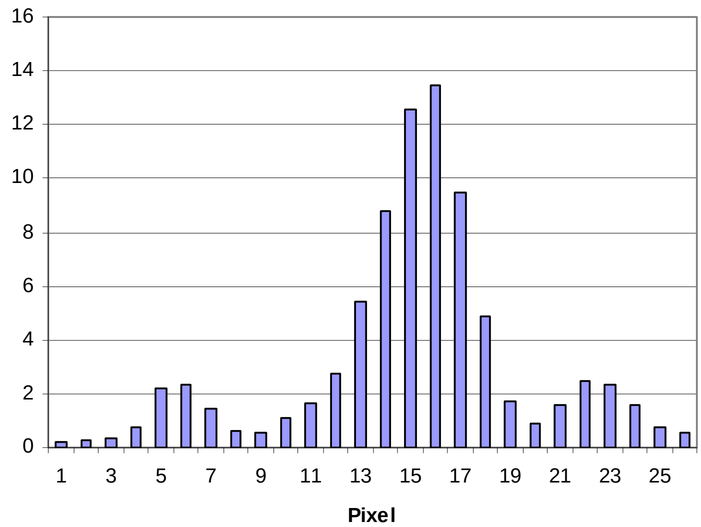

Fig.3. Horizontal section (in the x direction) through the difference image $\Delta I(x,y)$: The difference was produced between two images taken in series by the Art Plus. The section goes through an edge of a tooth in the marked area of Fig.1.

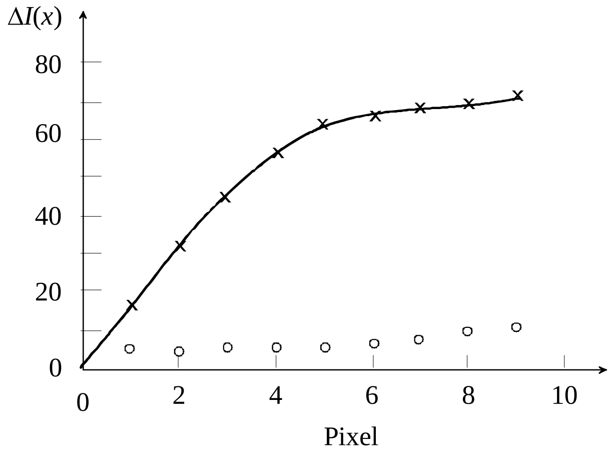

Fig.4. Relation between the maximum value (crosses) and the half-widths (circles) of the distribution, and shift (by a certain number of pixels), respectively, in the vicinity of the edge (Fig.1) in the difference image (Art Plus unit): The solid line is described by the function $f(x) = 0.0253x^4 - 0.4818x^3 + 1.1458x^2 + 15.2648x + 0.0245$.

The highest maximum value for the Art Plus unit was 59, which according to Fig.4, is equivalent to a shift of 4 to 5 pixels. The maximum for Pro Max was 62.27, which also just about equals 4 to 5 pixels. However, the fact that pixel size between the two units differs by a factor of 1.08 should be taken into account as well as the slight variations of edge form due to differences in resolution. The pictures that followed afterward showed noticeably smaller shifts. The maxima in the difference images of the Art Plus lay between 12 and 18 (shift of 1 pixel) and for the Pro Max, between 14 and 22 (shift of also about 1 pixel). While the shifts in the images produced by Art Plus always occurred in an either right or left direction across the entire image, the Pro Max also exhibited symmetrical displacements about the center axis.

4. Discussion and Conclusions

The visual impression was confirmed by the measured data. The Art Plus's CdTe-CMOS detector displays a high picture resolution compared to the other devices. In the case of image noise, the Art Plus distinguished itself, even though the R_{32x32} values can be used only for a rough appraisal. In this context it should be mentioned that R is dependent of the level of the gray value. Because it was not the areas with identical blackening that were compared but the locations in the image that were identical, the results are significant only to a limited degree. The differences in image noise are therefore also dependent upon the representation of the image as regards the gray scale values, although the histograms weakly vary with respect to the most frequent value. In Addition, the applied charge ranges between 63 mAs and 112 mAs. For the devices with high image quality, there may be a potential for dose optimization.

An interesting peculiarity having to do with image noise in every picture is the fact that the random variations (spots) extend over more than one pixel. When noise is caused by the detector's electronics, we should be able to find stochastic gray scale values changing from pixel to pixel. In the case of quantum noise, on the other hand, the florescence layer influences the gray scale modulation by scattering the light. Since the electrically charged particles released by the Art Plus's CdTe detector are directed toward the detector matrix without any transformation into light taking place, higher modulation frequencies should be expected. Other causes may be application of image filters (or noise filters) that smear the modulations. Some devices (Orthopos and Pro Max) give the impression that a combination of edge-sharpening filter and noise filter (in the sense of a pretreatment of the image) were used. The applied dose for the images differs remarkably between the tested devices (Tab.1). The low dose used for images taken with the Kodak 9000 or Cranex Novus device may affect resolution when applying extensive noise reduction. In this case, not the intrinsic resolution of the detector but the resolution of the entire system (possibly including automatic image pretreatment) is depending on the applied dose. In regard to an optimization of dose and required image quality, further investigations should address this problem.

With the exception of the first two pictures in each series, the image shifts measured in the Art Pro and Pro Max devices are small and amount to only a few pixels (a mechanical displacement of the skull phantom can be ruled out).

References

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