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Characteristics of a new cone beam computed tomography

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ABSTRACT

Purpose : To determine the physical properties of a newly developed cone beam computed tomography (CBCT).

Materials and Methods : We measured and compared the imaging properties for the indirect-type flat panel detector (FPD) of a new CBCT and the single detector array (SDA) of conventional helical CT (CHCT).

Results : First, the modulation transfer function (MTF) of the CBCT were superior to those of the CHCT. Second, the noise power spectrum (NPS) of the CBCT were worse than those of the CHCT. Third, detective quantum efficiency (DQE) of the indirect-type CBCT were worse than those of the CHCT at lower spatial frequencies, but were better at higher spatial frequencies. Although the comparison of contrast-to-noise ratio (CNR) was estimated in the limited range of tube current, CNR of CBCT were worse than those of CHCT.

Conclusion : This study shows that the indirect-type FPD system may be useful as a CBCT detector because of high resolution.

KEY WORDS : Tomography, Cone Beam Computed; Flat panel; MTF; NPS; DQE; SNR

Introduction

Computed tomography (CT) is widely used in medical and dental practice for the diagnosis of tumors, injuries and for clarifying the relationship between the lower third molars and mandibular canal. Shortcomings of CHCT are its lower resolution in the longitudinal direction and higher exposure dose. Recently, CBCT technique has been introduced in an effort to address some of the shortcomings of conventional CT for use in dental practice.[1-3] Their advantages suggests that they will also be useful in diagnosing dentomaxillofacial lesions.

FPDs of CBCT are becoming increasingly prevalent in the imaging market for many applications including those in medicine, veterinary medicine, and manufacturing. Studies are being performed to use these devices in all areas of clinical radiology including diagnostic radiography, fluoroscopy, and mammography, as well as research areas of tomosynthesis and CBCT.[4,5] FPDs[6] based on large-area active matrix thin-film transistor arrays, using either direct or indirect methods to convert x-rays into electric charge, have earned an increasing interest due to their high resolution[7] and absorptive properties, leading to a very high image quality.[8] Alternatives to these detectors, based on cheaper techniques, may be of interest to the medical imaging community due to high production costs of these detectors. The image quality of medical imaging for optimization was assessed using MTF, NPS, SNR, and DQE (Fig. 1).[9]

We have been developing a new CBCT system (RAYSCAN®, Ray Co., Ltd, Gyeonggi, Korea) for use in the dentomaxillofacial field. The goal of this study is to examine the configuration and physical properties of this new system by comparing the physical properties of indirect FPD of CBCT and SDA of CHCT.

Materials and Methods

1. Materials

We have developed a prototype CBCT that has a indirect-type FPD. The FPD is based on a matrix-addressed photodiode array fabricated by a complementary metal-oxide semiconductor (CMOS) process coupled to a terbium-doped gadolinium oxysulfide (Gd_2O_2S : Tb) scintillator as an x-ray-to-light converter (Fig. 2). Two x-ray units were used to expose test radiographic imagings (Table 1).

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2. Methods

1) Modulation Transfer Function (MTF)

The MTF is the most common metric to characterize the resolution of an imaging system.

The MTF (q, v) was measured by using the gold wire phantom (Fig. 3).

A MTF was calculated from the Fast Fourier Transform (FFT) of point spread function (PSF):[9-11]

$$\mathrm{MTF}(u)=\left|\int_{-\infty}^{\infty}\mathrm{PSF}(x)e^{-i2\pi ux}dx\right|$$

2) Noise Power Spectrum (NPS)

A quantitative representation of the noise properties of FPDs is commonly provided by the NPS.

The NPS was determined from the imagings of a water phantom (Fig. 4).

Two-dimensional NPSs were calculated over three areas in each radiograph employing:[12]

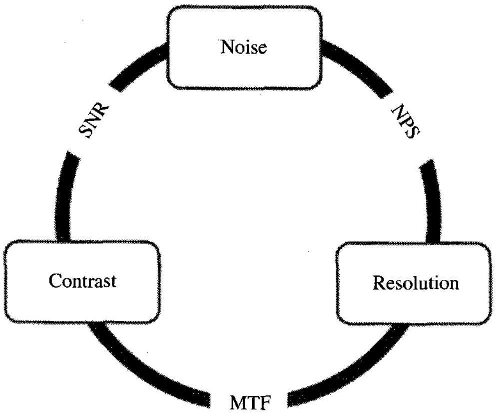

Fig. 1. Medical imaging concept overview.

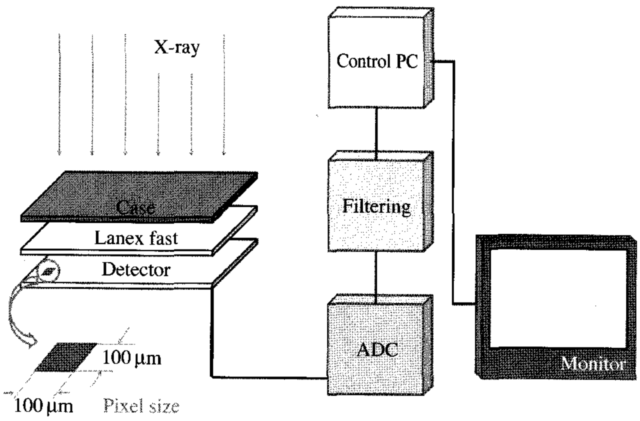

Fig. 2. The indirect FPD.

Table 1. Parameters of experimental system

System	GE HiSpeed Advantage® spiral CT	FPD based CBCT
Image size	512 × 512	2,048 × 2,048
Pixel size	0.371 mm × 0.371 mm	0.074 mm × 0.074 mm
Slice thickness	5 mm	0.074 mm
Scan time	1 sec	40 sec
Source to detector distance	1099.3 mm	651 mm
Source to object distance	630 mm	506 mm
Magnification ratio	1.74 : 1	1.29 : 1
Focal spot	0.7 mm × 0.9 mm	0.5 mm × 0.5 mm
Tube voltage	80 kVp/120 kVp	80 kVp/110 kVp
Tube current	40 mA/100 mA	5 mA/4 mA
FOV	190 mm (diameter)	152 mm (diameter)

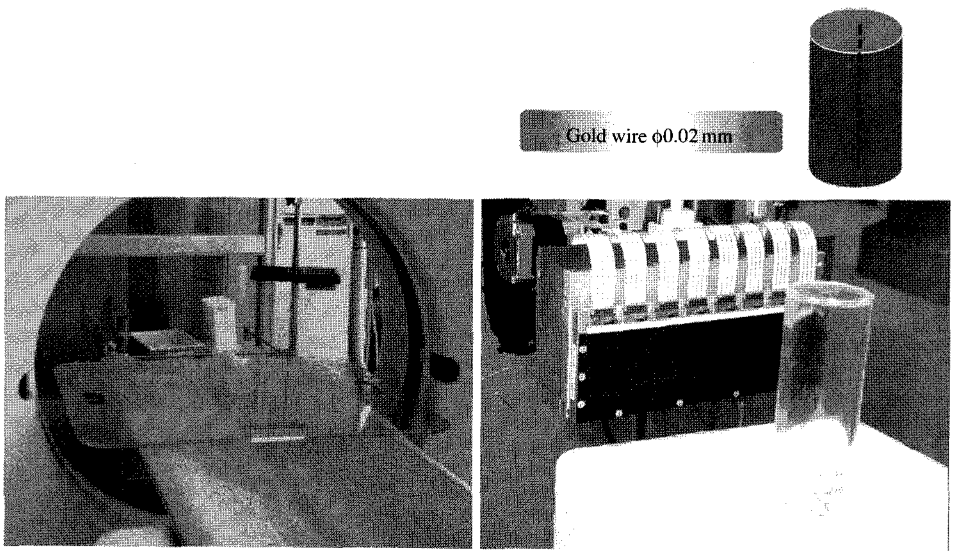

Fig. 3. Wire phantom scan for MTF experiment.

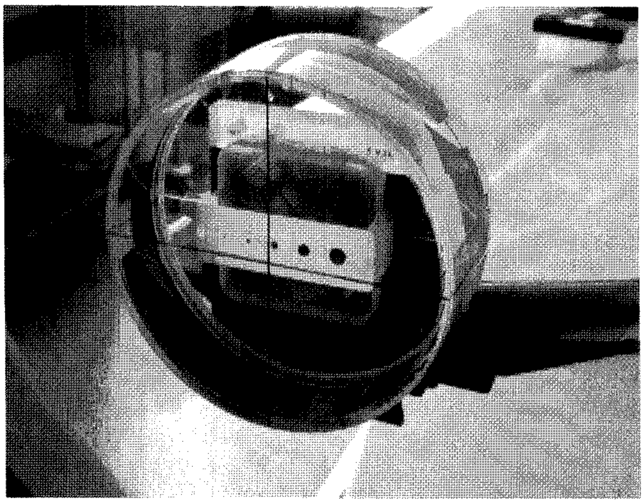

Fig. 4. Water phantom scan for NPS experiment.

$$\mathrm{NPS}(u, v) = \frac{\langle |FT(u, v)|^2 \rangle}{N_x N_y} \Delta_x \Delta_y$$

N_x and N_y are the number of elements, and Δ_x, Δ_y are the pixel size in x and y.

3) Detective Quantum Efficiency (DQE)

The DQE is commonly used as an image quality metric for signal-to-noise exposure efficiency for flat panel detectors.

The effective photon fluence for each of the exposures was calculated from the measured half value layer and exposures together with the mass absorption coefficient, DQEs were calculated using:[9-13]

$$\mathrm{DQE}(u, v) = \left(\frac{\mathrm{SNR}_{out}}{\mathrm{SNR}_{in}}\right)^2 = \frac{\mathrm{NEQ}(u, v)}{\bar{q}} = \frac{\mathrm{MTF}^2(u, v)}{\bar{q} \cdot \mathrm{NNPS}(u, v)}$$

where $\bar{q}$ is photon fluence [quanta/mm^2], NNPS is normalized NPS.

4) Contrast-to-Noise Ratio (CNR)

CNR was calculated using:[9]

$$\mathrm{CNR} = \left| \frac{(S_w - S_a)}{\sigma_w} \right|$$

where S_w and S_a are the signal of water and air, and σ_w is standard deviation in water.

Results

1. MTF

MTF values of CBCT were higher than that of CHCT at all spatial frequencies (Fig. 5).

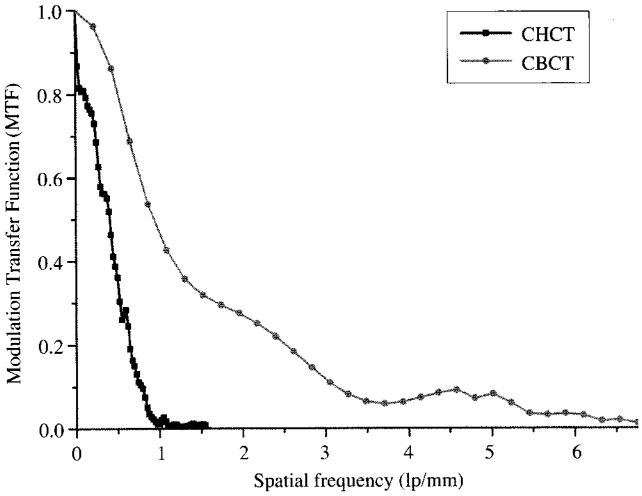

Fig. 5. MTF values of CBCT and CHCT.

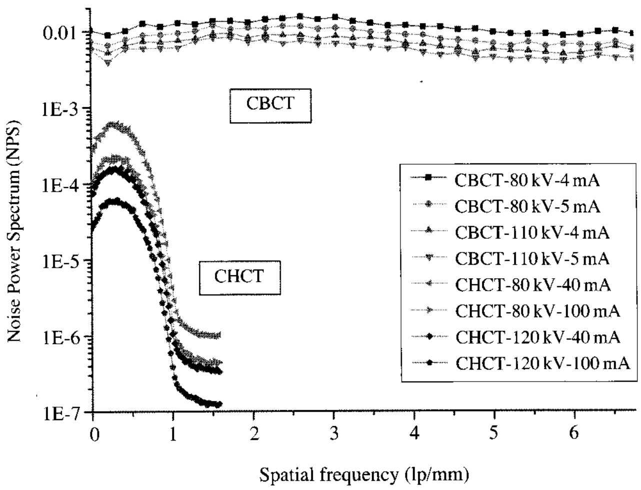

Fig. 6. NPS values of CBCT and CHCT.

2. Noise properties

The overall NPS values of CBCT were higher than that of CHCT. The noise power spectrum decreases with increased exposure and increased frequency (Fig. 6).

3. Combined signal and noise properties

Generally, DQE values of CBCT were higher than that of CHCT (Fig. 7).

4. CNR values

Although CNR values was estimated in the limited range of tube current, the overall CNR values of CBCT were much higher than that of CHCT (Fig. 8).

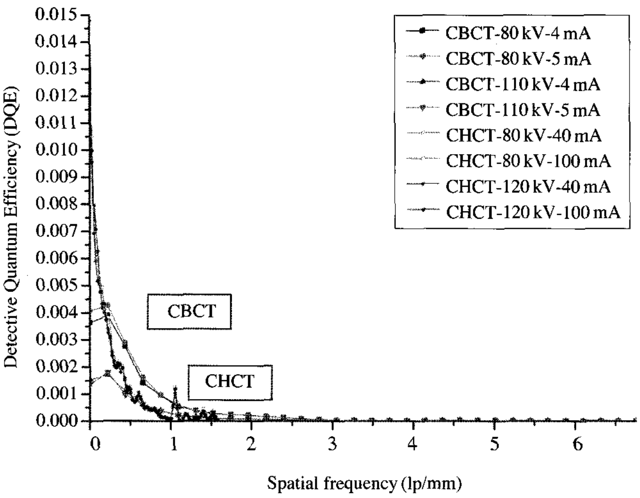

Fig. 7. DQE values of CBCT and CHCT.

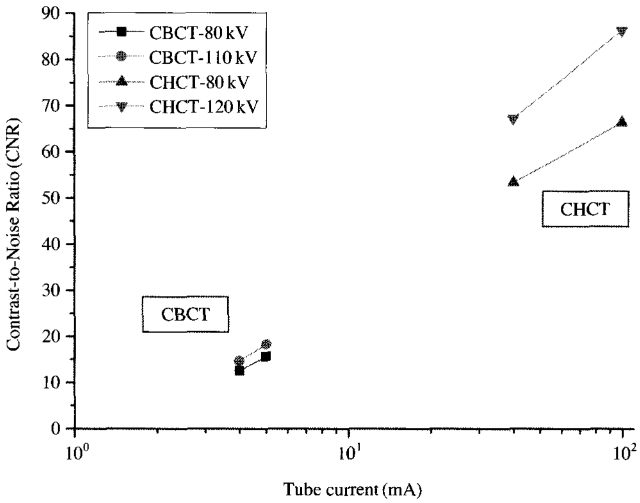

Fig. 8. CNR values of CBCT and CHCT.

Discussion

In this paper an evaluation and a comparison of the two detector systems of new CBCT and CHCT are presented. Three main factors affecting image quality are now generally considered to be contrast, sharpness (spatial resolution) and noise.[14] These basic imaging properties in radiographic images can be evaluated or characterized by gradient of the H & D curve, the MTF and the NPS.

The MTF can be obtained from the one-dimensional Fourier transform of the LSF or from the two-dimensional Fourier transform of the point spread function (PSF) of an imaging system.[15] The MTF represents the spatial frequency response of an imaging system such as a screen-film (S/F) system and the geometric unsharpness due to the focal spot of an x-ray tube.[14] In the previous measurement of the MTF of CBCT system revealed the high resolution in both the axial and longitudinal directions compared with CHCT.[16,17] Our study revealed that the overall MTF of the CBCT were superior to those of the CHCT as shown in Fig. 5. This suggests that this CBCT system will be useful for periodontal lesions which require high resolution.

The NPS represents the spatial frequency content of image noise. It can be determined based on the Fourier analysis of noise patterns obtained from uniform exposure of x-rays to an imaging system.[14] In conventional S/F systems and in digital radiography, the major source of noise in images is generally due to quantum noise or quantum mottle, which is caused by the statistical fluctuation of x-ray quanta absorbed by the S/F. In the previous measurement of CBCT, the image noise of CBCT was higher than those of CHCT.[18] In our present study, the digital and overall NPS of the CBCT were always worse than those of CHCT as shown in Fig. 6. This is likely to result from noise of the scintillator and high scattered radiation of this system. The influence of this high noise on the diagnos-tic capability of this system needs further clarification of CBCT.

A theoretical framework for image quality evaluation of medical imaging systems including conventional radiography, digital radiography, CT, MRI, radionuclide imaging and ultrasonography has been provided in ICRU Report No 54, 'Medical imaging: the assessment of image quality', published in 1996. The content of this report included the definition of NEQ and of DQE as a function of the spatial frequency.[19] The NEQ are defined by taking into account the system's gradient, the MTF and the NPS, and indicate the content of an image produced by uniform exposure incident on the imaging system.[14] The DQE is obtained from the ratio of the NEQ to the average number of x-ray quanta incident on the detector, and also from the ratio of the SNR of the output image to the SNR of the incident x-ray exposure. Thus, the DQE is an inherent measure of an imaging system for detecting a known signal, whereas the NEQ provides a measure of the potential quality of a uniformly exposed image in terms of the number of quanta contributing to the image.[14]

Our study revealed that the DQE of the CBCT were worse than that of CHCT at lower spatial frequencies below 0.25 mm^{-1}, but were better at higher spatial frequencies of 0.25-4.0 mm^{-1} as shown in Fig. 7. From our results, we expected that CBCT were useful machine by using digital image processing and so on in the radiology department.

Although the comparison of CNR was estimated in the limited range of tube current, CNR of CBCT were worse than that of CHCT as shown in Fig. 8.

Conclusively, the high MTF and superior DQE values of this indirect FPD suggested that this system may be useful as a CBCT detector. However, we must also point out that the influence of higher NPS and lower CNR values of the indirect FPD compared with SD needs further improvements and investigation.

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