J.Korean Asso. Radiat. Prot.
Vol.24 No.3 : 161-170(1999)

■論 文■

Comparison of Image Quality of the Amorphous Silicon DR System and the Film-screen Systems

Je-Woong Youn, Hyoung-Koo Lee, Tae-Suk Suh, Bo-Young Choe, Kyung-Sub Shin, In K. Mun[*], Hong-Kwon Kim, Yong-Woo Han[**], Seung-Bae Nam[**]
Catholic University, [*]Columbia University, [**]JM Technologies

비정질 실리콘 디지털 방사선 촬영기와 X-ray film과의 영상질 비교 평가

윤제웅 · 이형구 · 서태석 · 최보영 · 신경섭 · 문인기[*] · 김홍권
한용우[**] · 남승배[**]
카톨릭대학, [*]Columbia University, [**]JM Technologies

(1999년 8월 28일 접수, 1999년 10월 28일 채택)

ABSTRACT - System performances in terms of image quality between an amorphous silicon DR system and a conventional film-screen system were evaluated. Various aspects of image quality MTF (modulation transfer function), NPS (noise power spectrum), SNR(signal-to-noise ratio) and contrast were measured and calculated. The MTF of the DR system was comparable to the film-screen systems. The noise was mainly dominated by the quantum mottle in both systems and the electronic noise was found in the DR system. The contrast of the DR system was better than the film-screen systems by virtue of high sensitivity and image processing. Compared to the film-screen systems in general radiography, the DR system had similar resolution and showed better contrast with the same exposure condition after contrast manipulation. The results of this study provide some useful information about the performance of the DR system in connection with medical applications.

Key words : Digital Radiography, Amorphous Silicon Pixel Detector, Image Quality, Modulation Transfer Function, Noise Power Spectrum, Contrast

요약 - 비정질 실리콘 방사선 촬영기와 기존 X-ray filmrh과의 영상질 비교를 통하여 시스템의 성능을 평가하였다. 다양한 영상질 평가를 위하여 MTF (Modulation Transfer Function), NPS (Noise Power Spectrum), Contrast를 측정하여 계산하였다. 실험 결과 DR의 MTF는 기존 film-screen system과 유사하였다. Noise 특성은 두 시스템 모두 quantum noise가 주를 이뤘으며, 특히 DR에서는 전기적인 noise가 발견되었다. 또한 우수한 sensitivity 특성과 영상처리를 통하여 DR 시스템이 기존의 film-screen 시스템보다 높은 대조도를 보였다. 이와 같이 DR에서는 기존 film-screen 시스템과 유사한 해상도와 영상처리를 통해 같은 촬영조건에서도 향상된 대조도의 영상을 얻을 수 있었다. 본 연구를 통하여 의학적 활용과 관련된DR 시스템의성능에 대한 유용한 정보를 제공할 수 있으리라 기대한다.

중심어 : 디지털 방사선 촬영, 비정질 실리콘 방사선 계측기, 영상질, Modulation Transfer Function, Noise Power Spectrum, 대조도

INTRODUCTION

Digital radiography (DR) offers the potential of improved image quality, reduced patient dose, improved data storage and retrieval, and reduced cost by decreasing film usage. In recent years, a new class of real time, digital x-ray imaging devices using amorphous silicon pixel detectors has appeared. This device has the advantages of high sensitivity and short image acquisition time.

In this study we compared the amorphous silicon DR system with the old film-screen system in terms of image quality. For the comparative evaluation of the performance of the DR system, the modulation transfer function (MTF), noise power spectra (NPS), signal linearity to the exposure, signal-to-noise ratio (SNR) and contrast parameters of each system were studied and compared quantitatively.

Modulation Transfer Function

The modulation transfer function (MTF) is commonly used for evaluation of resolution characteristics of imaging systems. If a system is linear and stationary (space invariant), the description of a system response to a delta function completely describes the deterministic alteration of an entire image, which may be thought of as a superposition of numerous delta functions [1].

Line spread function is defined as intensity distribution in the image of an infinitely narrow slit. The exposure response of the screen-film system is nonlinear when it is expressed in terms of photographic density. Thus, film optical density is converted to corresponding effective exposure by macroscopic characteristic curve [2]. MTF is the amplitude of the Fourier transform of the line spread function. The MTF curve shows the ratio of output modulation to the input modulation expressed as a function of spatial frequency (cycles per millimeter). The greater the MTF for a system, the less blurring there is of the resulting image. Factors contributing to the MTF are light-diffusion in the screen, geometrical unsharpness caused by the size of focal spot [3].

MTF's in digital radiographic imaging systems need to be interpreted carefully. The assumption of shift-invariance is not true due to the discrete pixel size in the array. There is a phase dependence on the location of the edge with respect to the center of a pixel. In addition, undersampling of digital systems may introduce aliasing errors, which could lead to an incorrect interpretation of the resolution properties of a digital system. The presampling MTF is an appropriate measurement for digital imaging systems since it reduces the effect of aliasing using a "finely sampled" LSF which is obtained with a slightly angulated slit.

Radiographic mottle

Radiographic mottle is the spatial fluctuation of film density. Film graininess, nonuniformity of screen phosphor and quantum mottle contributes to overall radiographic mottle. Film graininess and nonuniformity of screen mottle is normally very small relative to quantum mottle. Quantum mottle is defined as the statistical fluctuations in the number of photons that contribute to image formation. When system speed is increased because of increased light output of the intensifying screen per absorbed x-ray or increased film speed, fewer x-ray photons are used to form image and, therefore, quantum mottle is increased [4]. In an x-ray imaging systems utilizing a scintillation phosphor, the signal-to-noise ratio can be expressed as

$$signal/noise = (NA_q I)^{1/2} \quad \text{.....................................(1)}$$

where A_q is the quantum absorption of the detector, I is the swank factor defined as

$I = M_1^2/M_2 M_0$ (M_0 , M_1 , M_2 : the respective moments of the scintillation pulse-height distribution) [5].

Noise power spectrum (NPS)

Among the descriptors used to define noise, the noise power spectrum not only indicates magnitude of noise but also shows the texture of the noise through its spatial frequency dependence. The NPS (or Wiener spectrum) describes the variance in amplitude of each frequency component of a system, and when integrated over all frequency elements gives a value equal to pixel rms noise [1]. The NPS is calculated as the ensemble average of Fourier power spectrums of images containing noise only, which is defined as

$$W(u,v) = \lim_{X,Y \to \infty} \left\langle \frac{1}{2X} \frac{1}{2Y} \left| \int_{-X}^{+X} \int_{-Y}^{+Y} \Delta D(x,y) e^{-2\pi i(ux+vy)} dxdy \right|^2 \right\rangle \quad \text{.........(2)}$$

where the symbol <> denotes the ensemble average, D(x,y) is density fluctuations of film and X, Y are window size.

MATERIALS AND METHODS

System Description

The list of the screen-film systems used in this work and their relevant properties are given as follows. A Lanex Regular screen (Kodak) was used in conjunction with the film and the amorphous silicon photodiode array. The array was synchronized with the x-ray source. The digital image was corrected for the offset, gain variation and dead pixels. Films used in our experiments were a type of high contrast and high resolution (Fuji Super HR-G). The X-ray source was a Toshiba model E7252X tube with a generator operated in single phase. The surface of either a film-screen cassette or an amorphous silicon detector was located at a distance of 180cm from the x-ray source. The films were developed by a Kodak RP X-OMAT processor(Model M6B) at 33.4 ℃. The film images were scanned by a film-scanner (Vidar, VXR-12 model) and the output image has a pixel depth of 12-bit.

Modulation Transfer Function (MTF)

We used a 10-㎛ slit camera (Nuclear Associates) which is made of 1.5 mm Tantalum jaw. Each screen-film system and the DR system were exposed at 40, 80, 120 kVp. The sampling distance used were 0.127 mm which is the pixel pitch of DR and 0.085 mm (300 dpi) in the film-screen system. The LSFs of a film-screen system were obtained by conversion of the transmittance to the effective exposure by means of the characteristic curve [6]. Also the base value was subtracted from the original LSF and the resulting value was normalized to the maximum value. The discrete sampled LSFs were fitted to the exponential curve to reduce aliasing effect [7,8]. Finally, MTF was derived from the Fourier transform of the obtained LSF.

Noise Power Spectrum (NPS)

To determine the noise power spectrum of a given film-screen combination and a DDR system, a direct digital method was used [9]. The center 10241024 portion of noise image was selected and subdivided into 64 128128 ROIs. The 2D FFT of each ROI was computed to obtain the squared Fourier magnitudes. The resulting 2D noise power spectrum was determined after averaging 64 NPS samples.

Contrast

Aluminum step wedge (20 steps, 1mm/step) was used to evaluate the contrast of two systems. For the comparison of the film-screen and DR system the step wedge images were acquired at the same exposure condition. Each step value was determined by averaging the corresponding step image.

RESULTS

The radiation response of each system as a function of exposure was measured for 40, 60, 80, 100 and 120 kVp. The DR data showed a linear response followed by saturation of the pixel as shown in Figure 1. The slopes showed a clear dependence on beam energy. In a film-screen system the optical density was measured and plotted against its corresponding exposure in Figure 2. The range of exposures, over which the film image is radiographically useful, is narrower than DR.

The noise measured for a film-screen system and DR was plotted versus signal. The noise of DR system increases as the signal increases and suddenly decreases at the saturation level as shown in Fig. 3. In the film-screen system the noise has the tendency of increasing with the film optical density. The noise power spectra were obtained for each film-screen system and a DR system at the same exposure condition as shown in Fig 4. Fig. 5 shows the NPS of two sets of images, one irradiated and one with no radiation in the DR system. System noise of the DR is small compared to a quantum noise and shows uniform distribution with respect to the spatial frequency. Fig. 6 shows the NPS obtained with a DR system and a screen-film system at the same exposure condition. Both NPS have a tendency to decrease as a spatial frequency increases. The value of NPS at low spatial frequencies in a screen-film system is higher than that in a DR system.

Fig. 7 shows MTFs for the screen-film and DR system. There was little difference in the MTF's between two systems. Contrast was measured for each system and plotted versus the number of aluminum steps. The contrast after contrast stretching were also compared to the original. At the relatively low tube voltage the contrast of the film-screen systems was slightly better than that of DR. But at high kVp DR showed much better contrast than film-screens as shown in Fig. 8. In any case, however, the contrast of DR images are superior to film images after contrast stretching.

DISCUSSION

The response of a pixel is highly linear to the exposure up to saturation. As signal level increases, the electric field across the photodiode decreases which increases the amounts of charge trapping and leads to the loss of linearity and saturation [10]. The slopes show a clear dependence on beam energy. These trends are related to the fact that the generation of light is the result of the absorption of x-ray energy in the phosphor and the increase depth of x-ray penetration in the phosphor screen with the tube voltage. For Lanex screen, large peak of the x-ray energy absorption appears at Gadolinium K-edge, which is about 50 keV. Thus, the portion of the energy spectrum in this K-edge region increases with beam energy (kVp), which results in a larger signal per unit exposure for higher kVp [11].

The dependence of the noise on the beam energy is related to the screen property. The noise produced by a screen increases with the absorbed x-ray photons in the screen [5]. The main source of noise is the quantum mottle. It follows the Poisson distribution and thus has the uniform noise power spectrum. But the NPS obtained from the experiments slowly decrease with a spatial frequency, because the NPS is proportional to the square of the system MTF [4]. The system noise of DR, which is caused by the TFT switching etc, is small compared to the quantum noise with irradiation and thus, the quantum noise is the dominant source of noise in DR.

When using a same Lanex Regular screen, the MTF of DR is similar to that of film-screen system. It means that the main factor, which deteriorates the system MTF, is the diffusing characteristics of the screen and that the current pixel size of detector is small enough to produce comparable resolution to the screen-film system up to the Nyquist frequency.

The contrasts of the DR and film-screen systems are obtained and compared. The raw data of DR contrast look poor due to the relatively high background gray level at low exposure, at which the optical density of the film-screen system rapidly saturated to a saturation level. But the contrast of DR can be easily enhanced by the image processing technique, such as histogram equalization or specification. Also DR can produce the same contrast as film by means of the histogram specification.

CONCLUSION

We have measured the NPS, MTF, contrasts of film-screen systems and the DR system. Compared to film-screen systems used in general radiography, the DR system has similar resolution and shows better contrast in the same exposure condition after a simple image processing and thus, x-ray exposure reduction is expected. Also, film imaging is often limited by a lack of exposure latitude but DR shows excellent image contrast over wide latitude of x-ray exposures.

REFERENCES

1. J. T. Dobbins III, "Effects of undersampling on the proper interpretation of modulation transfer function, noise power spectra, and noise equivalent quanta of digital imaging systems", *Med Phys*, 22(2), pp. 171-181 (1995).
2. J. C. Dainty, R. Shaw, *Image Science*, pp. 232-275, Academic Press, London(1974).

3. G. Lubberts, K. Rossmann, "Modulation transfer function associated with geometrical unsharpness in medical radiography.", *Phys Med Biol,* 12(1), pp. 65-77(1967).
4. K. Rossmann, "Spatial fluctuations of x-ray quanta and the recording of radiographic mottle.", *Am J Roentgenol,* 90(4), pp. 863-869(1963).
5. R. K. Swank, "Absorption and noise in x-ray phosphors", *J Appl Phys,* 44(9), pp. 4199-4203(1973).
6. K. Rossmann, G. Lubberts, H. M. Cleare, "Measurement of the line spread-function of radiographic systems containing fluorescent screens.", *J Optic Soc Am,* 54, pp. 198-204(1963).
7. Hiroshi Fujita, Du-Yih Tsai, "A simple method for determining the modulation transfer function in digital radiography", *IEEE Trans Med Imag,* 11(1), pp. 34-39(1992).
8. F. F. Yin, M. L. Giger, K. Doi, "Measurement of the presampling modulation transfer function of film-digitizers using a curve fitting technique", *Med Phys,* 17(6), pp. 962-966(1990).
9. J.T. Dobbins III, D. L. Ergun, Lois Rutz, D. A. Hinshaw, Hartwig Blume and D. C. Clark, "DQE(f) of four generations of computed radiography acquisition devices", *Med Phys,* 22(10), pp. 1581-1593(1995).
10. L. E. Antonuk, Y. El-Mohri, J. H. Siewerdsen, J. Yorkston, W. Huang, and V. E. Scarpine, "Empirical investigation of the signal performance of a high-resolution, indirect detection, active matrix flat-panel imager (AMFPI) for fluoroscopic and radiographic operation", *Med Phys,* 24(1), pp. 51-70(1997).
11. L. E. Antonuk, J. Siewerdsen, J. Yorkston, and W. Huang, "Radiation response of amorphous silicon imaging arrays at diagnostic energies.", *IEEE Trans Nucl Sci,* 41, pp. 1500-1505(1994).

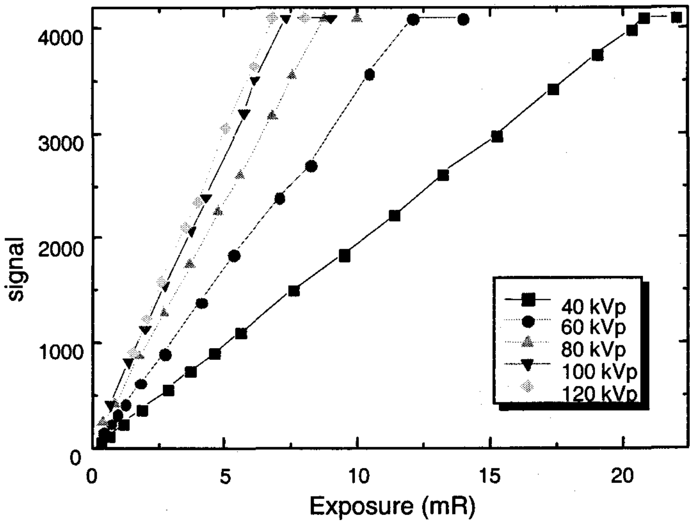

Fig. 1. Exposure response of the DR system

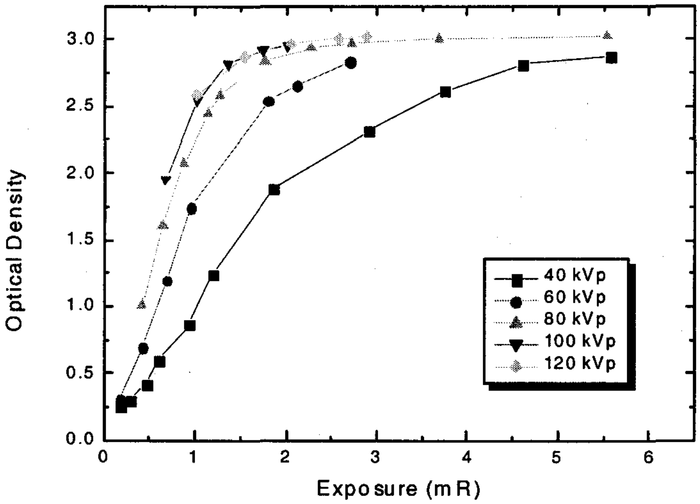

Fig. 2. Exposure response of the film-screen system

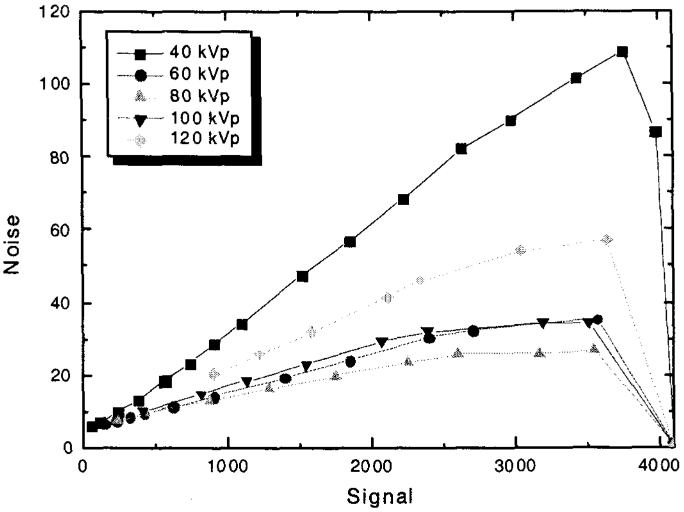

Fig. 3. Noise versus signal in DR

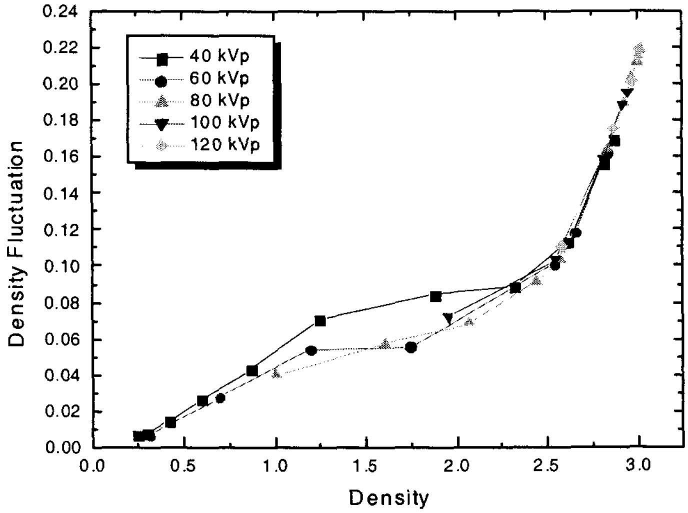

Fig. 4. Noise versus signal in the film-screen system

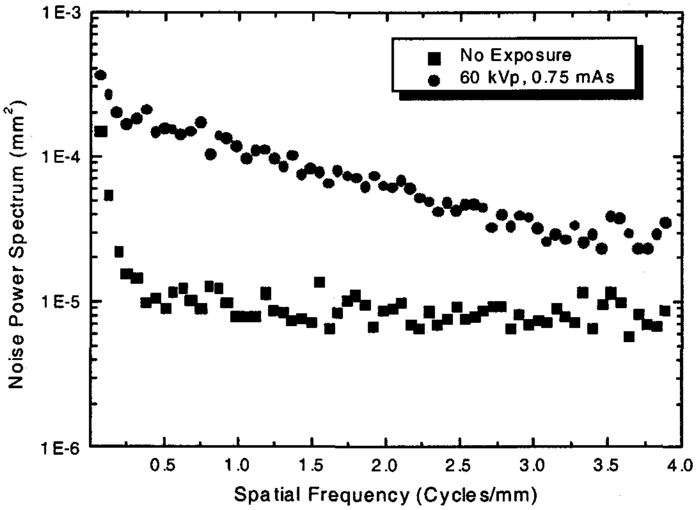

Fig. 5. Noise power spectrum of DR

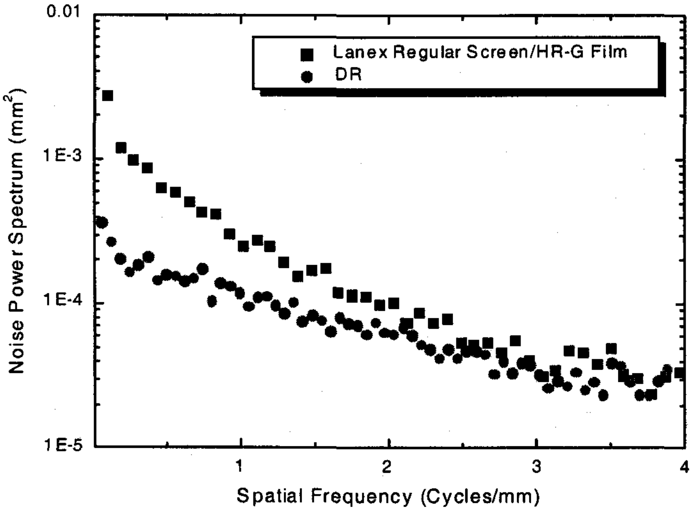

Fig. 6. Comparison of NPS in DR and film-screen (exposed at 60kVp, 1.25mAs)

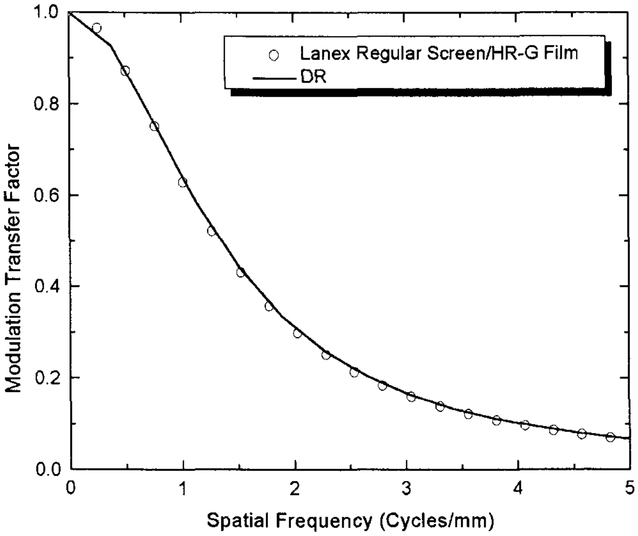

Fig. 7. Comparison of MTF in DR and film-screen system

Fig. 8. (a)

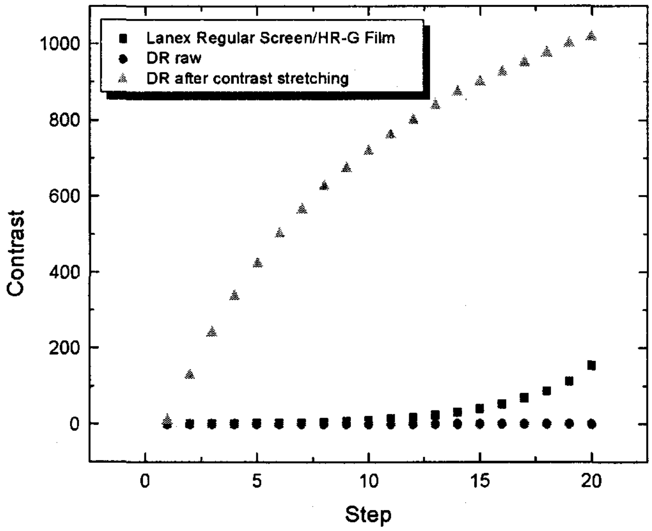

Fig. 8. (b)

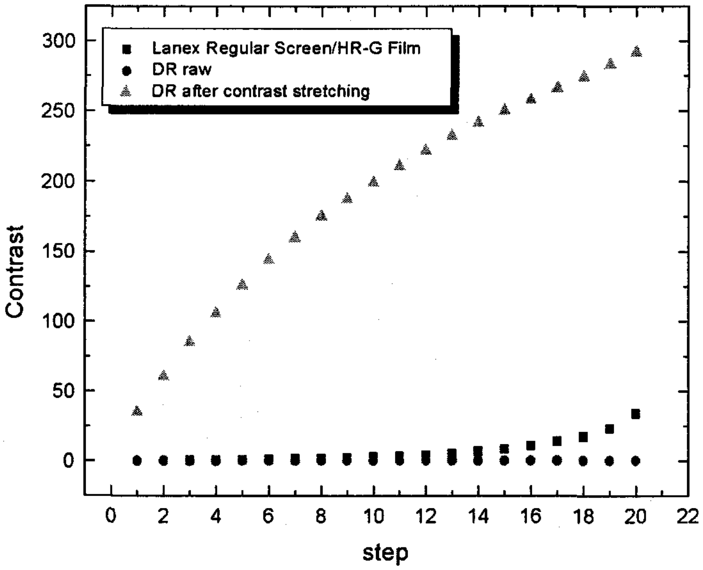

Fig. 8. Contrast results of DR and film-screen system with exposure condition (a) 80kVp, 1mAs (b) 120kVp, 0.375mAs