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Bremsstrahlung X-ray Spectra for Enhanced K-edge Angiography

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Abstract

Energy-selective enhanced K-edge angiography utilizing a conventional x-ray generator is described. The x-ray generator is SOFRON NST-1005, and the maximum tube voltage and current are 100 kV and 5 mA, respectively. In the present research, the tube voltage ranged from 45 to 65 kV, and the tube current was regulated to optimum values. The exposure time is controlled in order to obtain optimum x-ray intensity. At a charging voltage of 60 kV, the x-ray intensity rate obtained using an aluminum and a barium sulfate filters were 58.4 and 51.6 μGy/s at 0.7 m per pulse, respectively, and the dimensions of the focal spot were approximately 1 × 1 mm. Angiography was performed using both the aluminum and the barium sulfate filters with a charging voltage of 60 kV.

Keywords: angiography, aluminum filtering, barium sulfate filtering, quasi-monochromatic x rays, iodine-based contrast medium

1. Introduction

Monochromatic parallel radiography using a synchrotron in conjunction with single crystals continues to be the major tool used in x-ray phase imaging[1,2] and enhanced K-edge angiography.[3,4] In cases where the phase imaging is employed, the spatial resolution can be improved, and the number of tissues which can be observed using x rays increases.

To perform high-speed radiography, several different flash x-ray generators have been developed,[5] and soft generators[6-10] with photon energies of lower than 150 keV can be employed to perform biomedical

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radiography. In order to produce monochromatic x rays, plasma flash x-ray generators[11-15] are useful, since quite intense and sharp characteristic x rays such as lasers have been produced from weakly ionized linear plasmas of nickel, copper and molybdenum.

Parallel beams with photon energies of approximately 35 keV have been employed so as to perform angiography, since these beams are absorbed effectively by an iodine-based contrast medium. Subsequently, K-series characteristic x rays with energies of approximately 35 keV are also useful, and fine blood vessels were observed with high contrasts. In view of this situation, we have developed x-ray generators with cerium-target tubes[16,17] which can produce Kα rays of 34.6 keV. Because bremsstrahlung x rays of approximately 35 keV also useful in order to perform high-contrast angiography, the development of optimum filters for producing narrow-energy-latitude bremsstrahlung x rays are desired in cases where a conventional tungsten target is employed.

In this research, we employed a tungsten-target x-ray tube and performed a preliminary study on enhanced angiography achieved with bremsstrahlung x rays with narrow-photon-energy latitudes produced by filtering in conjunction with a computed radiography (CR) system.[18]

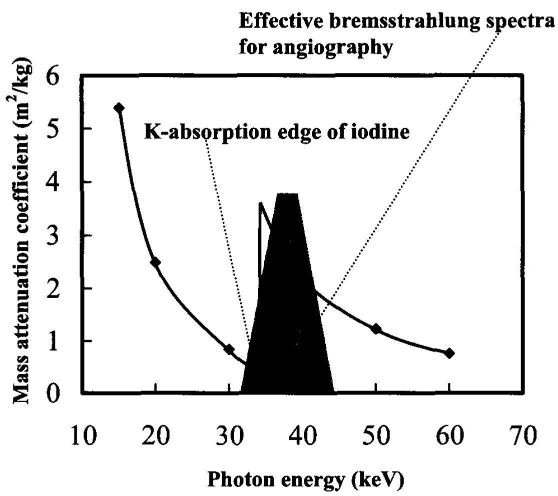

Fig. 1: Mass attenuation coefficients of iodine and effective bremsstrahlung x rays for enhanced K-edge angiography.

2. Principle of K-edge angiography

Figure 1 shows the mass attenuation coefficients of iodine at the selected energies; the coefficient curve is discontinuous at the iodine K-edge. The effective bremsstrahlung x-ray spectra for K-edge angiography are shown above the iodine K-edge. Because iodine contrast mediums with a K-absorption edge of 33.2 keV absorb the rays easily, blood vessels were observed with high contrasts.

3. Experimental setup

A steady state x-ray generator (SOFRON NST-1005) is shown in Fig. 2, and the maximum tube voltage and current are 100 kV and 5 mA, respectively. In this experiment, the tube voltage applied was from 45 to 65 kV, and the tube current was regulated to within 5.0 mA (maximum current) by the filament

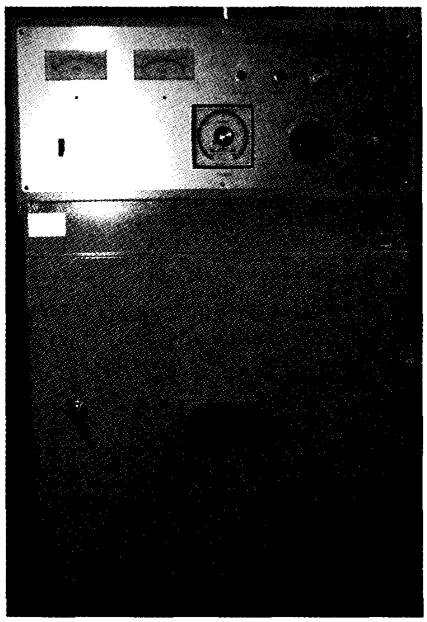

Fig. 2: X-ray generator.

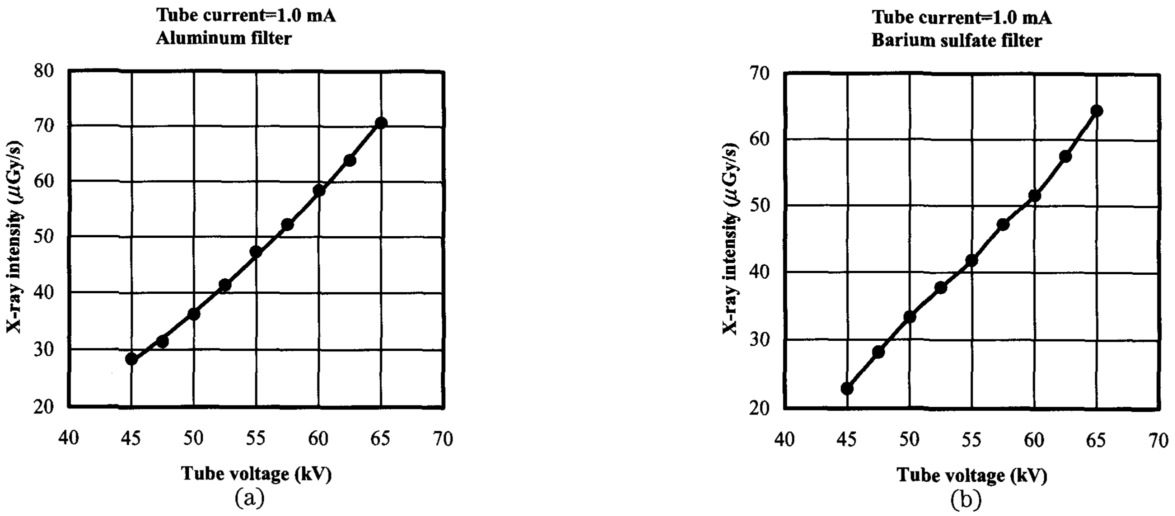

Fig. 3: X-ray intensity at 1.0 m per pulse with changing charging voltage (a) using aluminum filter and (b) using barium sulfate filter.

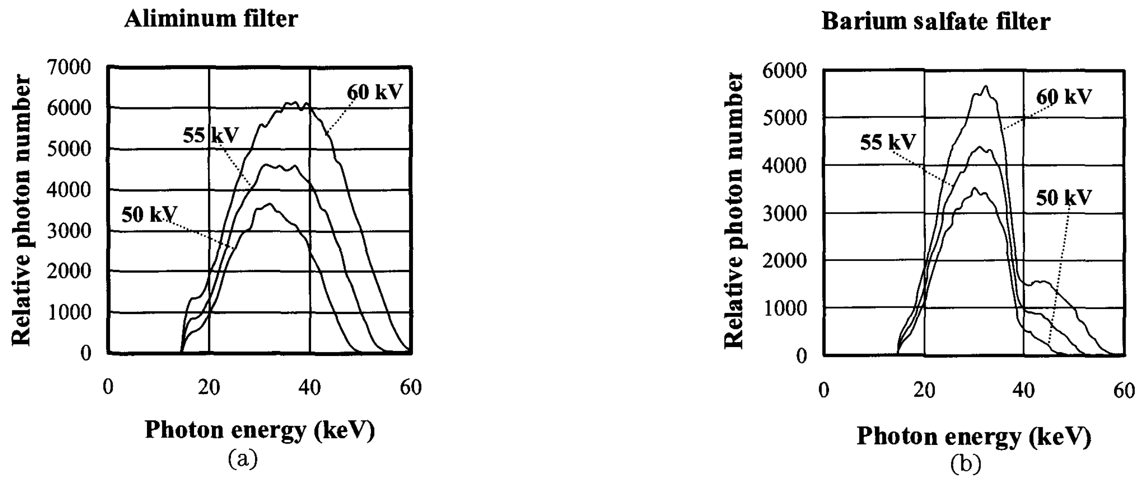

Fig. 4: X-ray spectra using (a) aluminum filter and (b) barium sulfate filter.

temperature. The exposure time is controlled in order to obtain optimum x-ray intensity. In designing the filter, the surface density of the barium sulfate powder is important, since the x rays are absorbed effectively by the powder as compared with the PMMA resin.

4. Characteristics

4.1 X-ray intensity

Figure 3 shows the x-ray intensity at 0.7 m per pulse measured by a Victoreen 660 ionization chamber. The x-ray intensity increased with increasing the tube voltage. At a tube voltage of 60 kV, the x-ray intensities obtained using an aluminum filter and a barium sulfate filter were 58.4 and 51.6 μGy/s, respectively, at 0.7 m from the x-ray source.

4.2 X-ray spectra

In order to measure x-ray spectra, we employed a cadmium tellurium detector (CDTE2020X, Hamamatsu Photonics K.K.) (Fig. 4). Compared with a germanium detector, this detector has a lower energy resolution of 1.7 keV. When the tube voltage was increased, both the maximum photon energy and the intensities of bremsstrahlung x rays increased, and the photon energy of the spectrum peak also increased. The 3-mm-thick aluminum filter attenuated the low-photon-energy bremsstrahlung x rays. The barium sulfate filter, with a surface density of approximately 10 mg/cm^2, significantly attenuate the spectra above the barium K-edge energy of 37.4 keV. The areas under the spectral curves correlate closely to the total x-ray intensities shown in Fig. 3

5. Angiography

The angiography was performed by the CR system (Konica Regius 150) using the filters with a tube voltage of 60 kV, and the distance between the x-ray source and the imaging plate was 0.7 m. The image contrast hardly varied even when the filter was changed.

Figure 5 shows radiograms of tungsten wires coiled around a rod made of polymethyl methacrylate using the aluminum filter. Although the image contrast increased with increases in the wire diameter, a 50-μm-diameter wire could be observed.

Figures 6 and 7 show angiograms of a rabbit thigh (barium sulfate filter) and a dog heart (aluminum filter), respectively. In angiography, iodine-based microspheres of 15 μm in diameter were used, and fine blood vessels of approximately 100 μm were visible.

6. Discussion

Concerning the spectrum measurement, we obtained bremsstrahlung x rays with narrow energy latitudes using both the aluminum and the barium sulfate filters. When the aluminum filter was employed with a tube voltage of 60 kV, the peak photon energy of spectra was approximately 35 kV.

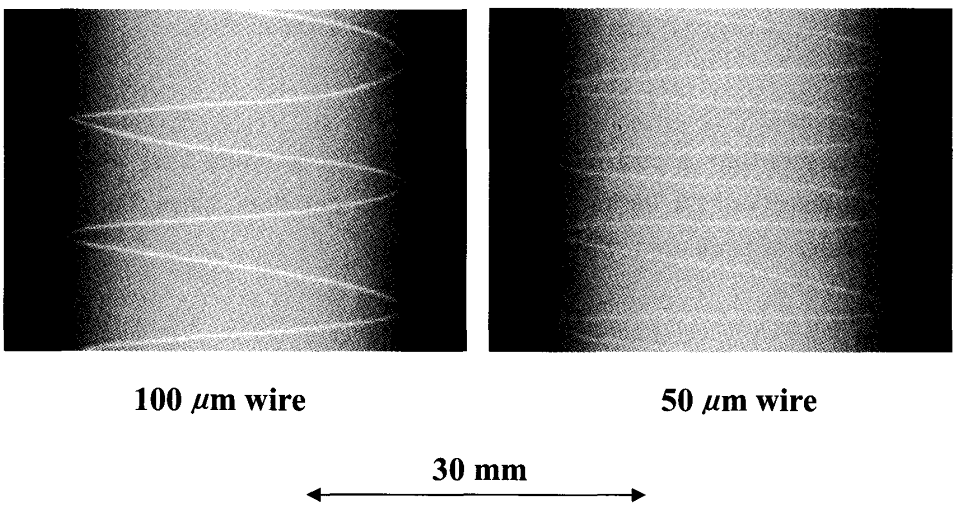

Fig. 5: Radiograms of tungsten wires coiled around rod made of polymethyl methacrylate using aluminum filter.

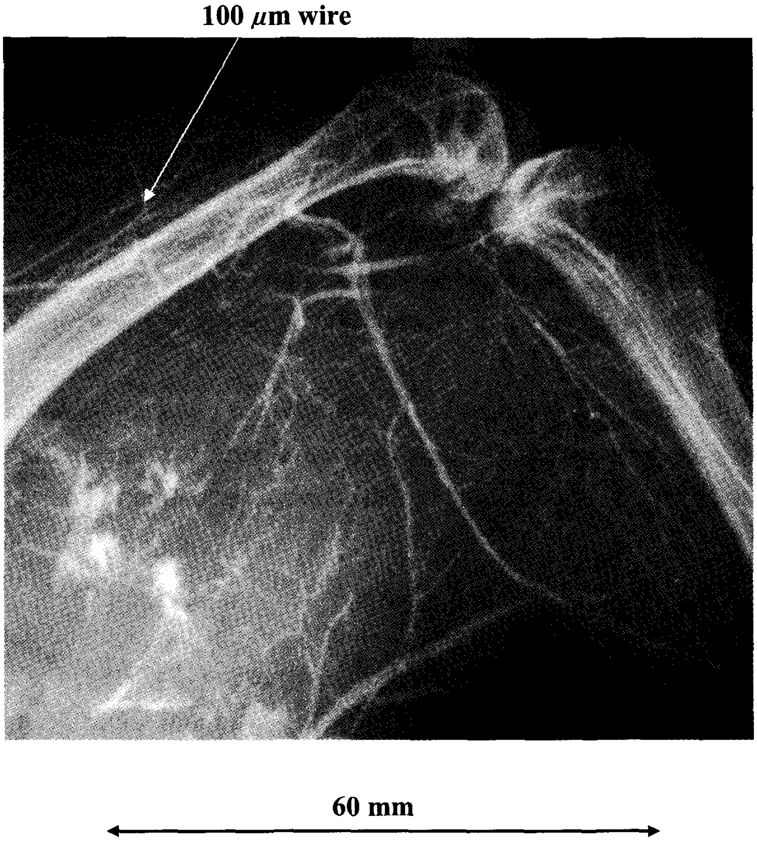

Fig. 6: Angiograms of rabbit thigh achieved with barium sulfate filter

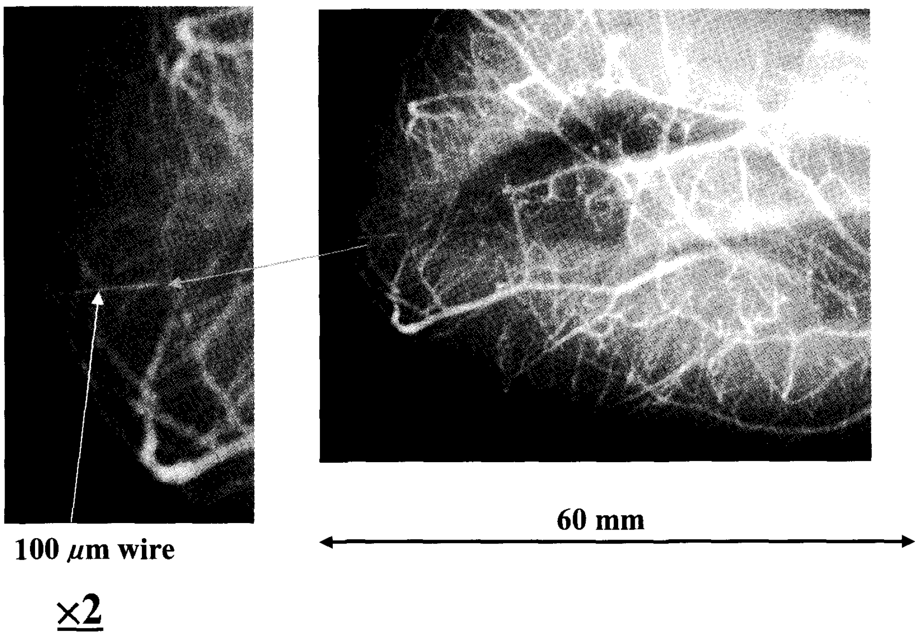

Fig. 7: Angiogram of dog heart with aluminum filter.

Therefore, the filter thickness should be increased as much as possible to decrease bremsstrahlung x rays of lower than K-absorption edge of iodine. Subsequently, using the barium sulfate filter, because the peak photon energy was nearly equal to the K-edge, aluminum filtering should be employed. In addition, cerium oxide filter is also useful in order to increase the peak energy and to decrease the low-photon-energy bremsstrahlung x rays.

In the present research, we employed a low-dose-rate x-ray generator in order to measure the x-ray spectra using a semiconductor detector. However, conventional medical x-ray generators with high dose rates can be employed to increase the tube current and to decrease the exposure time at a constant tube voltage.

With recent advances in angiography using MRI, if the density of gadolinium-based contrast media increases, enhanced K-edge angiography utilizing monochromatic x-ray generators, which produce Kα rays of ytterbium, tantalum, and tungsten, will be fairly useful technique to decrease the absorbed dose during angiography.

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