9. Medical Applicatons

9-1. Clinical Application of Synchrotron Radiation to Intravenous Coronary Angiography at PF-AR

The use of coronary angiography (CAG) is indispensable for the diagnosis of coronary artery disease. However, because CAG entails the injection of a contrast agent directly into a coronary artery, it is potentially hazadous, and may cause the patient physical and mental distress. It also requires the careful efforts of physicians. If CAG could be performed more easily, both the patients and the physicians would benefit. Accordingly, intravenous CAG with synchrotron radiation was developed to minimize the disadvantages of the intra-arterial procedure for CAG. Because high-intensity and monochromatic X-rays are obtainable from synchrotron radiation, coronary angiography by intravenous injection of a contrast medium (IVCAG) becomes possible. We obtained two-dimensional monochromatic X-rays from synchrotron radiation and developed a dynamic IVCAG. We succeeded in its clinical application in 1996 [1,2], and are improving and confirming the usefulness of the dynamic IVCAG.

Patients diagnosed, or suspected, of having coronary artery disease were recruited for the dynamic IVCAG. Synchrotron radiation was reflected asymmetrically with a silicon crystal to produce a wide (130 mm × 80 mm) and monochromatic (37 keV) X-ray beam with an energy level just above the iodine K-edge to achieve high sensitivity to an iodine contrast medium. Patients received an intravenous injection of 35~40 ml of iodine contrast medium, and then irradiation was performed for 4~6-ms periods at 100-ms intervals with a shutter for dynamic angiography at 10 images/s. Images were acquired with an image intensifier and recorded with a digital imaging system. IVCAG was repeated in 3 or 4 projections. The total irradiation doses used for IVCAG were less than those for conventional CAG.

Thirty-three patients underwent dynamic IVCAG. Dynamic IVCAG permitted visualization of the right coronary artery (segment 1 to 3 in American Heart Association's [AHA] classification), the left main trunk (segment 5 in AHA classification) and the left anterior descending (LAD) coronary artery (segment 6 to 8 in AHA classification) in all patients (Figs. 1 and 2). The proximal left circumflex (LCx) coronary artery (segment 11 in AHA classification) was visualized in all patients, but the distal LCx coronary artery was visualized in about 50% of the patients due to overlapping with the left ventricle. As a complication, only 2 patients showed mild skin eruption by the contrast medium. According to a questionnaire, this imaging has been well accepted by the patients.

Our data suggest that dynamic IVCAG was confirmed to be useful in evaluating coronary artery disease and in reducing the burdens of patients in

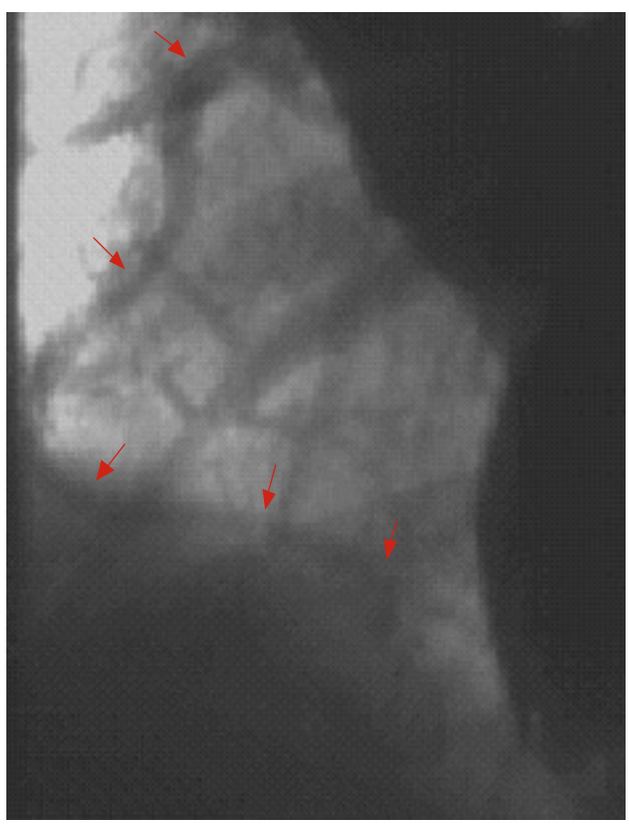

Figure 1.
Representative image of a left anterior oblique projection of a right coronary artery obtained by IVCAG. The right coronary artery is visualized from its ostium to its horizontal portion (from segment 1 to 3 in AHA classification).

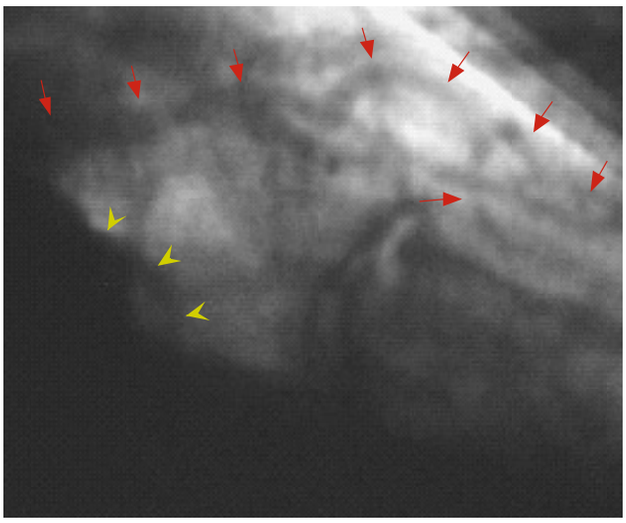

Figure 2.
Representative image of a right anterior oblique projection of a left coronary artery obtained by IVCAG. The red arrows indicate the left main trunk and the left anterior descending coronary artery (from segment 5 to 8 in AHA classification); the yellow arrows indicate the proximal portion of the left circumflex coronary artery (segment 11 in AHA classification).

receiving coronary angiography. In order to increase the contrast image of IVCAG, the intensity of the synchrotron radiation should be increased, and a high-performance detector having a higher definition and a wide dynamic range is desired in future. Also, an extension of the width of the synchrotron beam to 130 mm would be efficient to reduce the irradiation frequency, because the right and left coronary arteries can be simultaneously obtained by once injection. Therefore, the dynamic IVCAG can be easily used for screening and follow-up of coronary artery disease.

S. Ohtsuka[1], I. Yamaguchi[1], J. Wu[1], T. Takeda[1], Y. Itai[1], A. Maruhashi[1], K. Hyodo[2] and M. Ando[2] ([1]Univ. of Tsukuba, [2]KEK-PF).

References

[1] K. Hyodo et al., J. Synchrotron Rad. 5 (1998) 1123.
[2] S. Ohtsuka et al., Brit. J. Radiol. 72 (1999) 24.

9-2. Development of Phase Contrast Radiography and its Application to the Diagnosis of Orthopedic Diseases

Since the discovery of X-rays in 1895 up until recently, all practical uses of radiography for human imaging have been based on the X-ray absorption contrast. The images contrast of this method can be explained by an alteration of the amplitude of the X-ray wave when an object is placed before it. However, it is difficult to detect the low X-ray absorption and details of small objects, like micro-fractures of fingers or small calcium deposition in breast cancer at early stages.

A novel imaging method, called the X-ray phase-contrast radiography, using the spatial coherence of X-rays, was performed by a micro-focus tube [1]. The image contrast of this method can be explained by a shift of the phase of the X-ray waves when different objects are placed before it; i.e., the incident X-ray refraction at the boundary of objects that have different X-ray refractive indices. The fringe image of the object was enhanced by the refraction as a black-white contrast on an imaging device, like X-ray film. The synchrotron source is also suitable for phase-contrast radiography because of its high degree of spatial coherence of incident X-rays with high intensities. A sufficient size of the exposure field for human imaging is obtained by X-ray diffraction techniques with asymmetric crystals. Phase-contrast radiography using monochromatic synchrotron X-rays has been developed.

The experimental arrangement of the radiography at AR-NE5A is shown in Fig. 3. Four asymmetric crystals of Si 220 greatly improve the degree of spatial coherence of X-rays. Two pairs of double-crystals in the (+, –) arrangement were employed. These also magnify the beam size; one upstream pair corresponds to the magnification of the vertical beam size and the other (downstream) for the horizontal beam. The sample was human dried proximal phalanx with micro-fractures [2]. The X-ray image was stored on mammography film without an intensifying screen. The phase contrast was enhanced at a suitable sample-to-film distance of Z. The typical value of Z to visualize the clear micro-fracture line ranged from 0.3 m to 1.5 m at an incident X-ray energy of 30 keV. The X-ray phase contrast images taken at Z~0.5 m and Z~0 m are shown in Figs. 4 and 5, respectively. The micro-fractures are clearly seen only in Fig. 4. This high image quality has never been achieved by the conventional method.

Phase-contrast radiography using synchrotron X-rays should be a powerful tool for the diagnosis

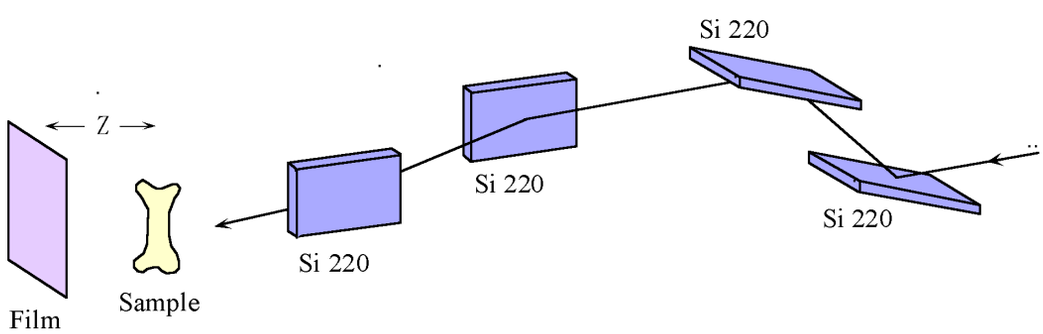

Figure 3.
Experimental arrangement of the radiography at AR-NE5A. The magnification of the beam size is defined by the inverse of the asymmetric factor (b), $b = \sin(\theta_B-\alpha)/\sin(\theta_B+\alpha)$, where θ_B is the Bragg angle at the crystal and α is the angle between the crystal surface and the diffraction planes. Also, this leads to an improvement in the beam divergence corresponding to the beam coherence by a factor of $\sqrt{b}$. The values of b were 0.17 (1st) and 0.20 (2nd) for the vertical, 0.09 (3rd) and 0.11 (4th) for the horizontal, respectively.

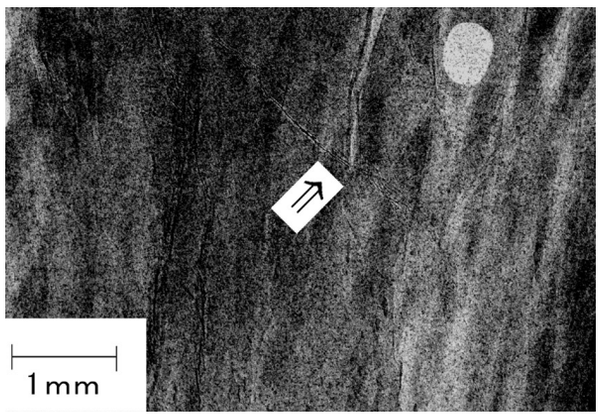

Figure 4.
Frontal X-ray image of dried bone at Z~0.5 m. The micro-fracture running transversely was clearly observed (⇒). The bone trabeculae, important in the diagnosis of the bone diseases, were also clearly observed.

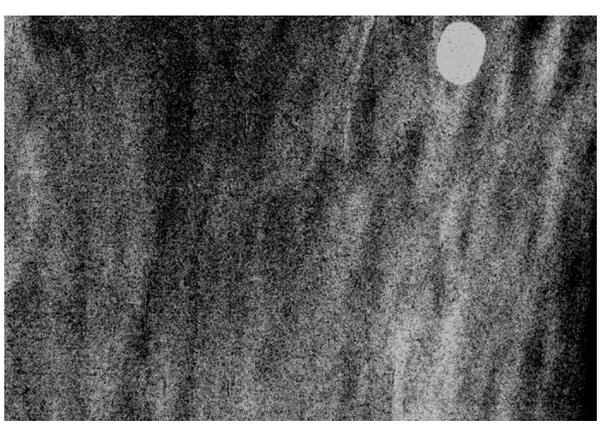

Figure 5.
Frontal X-ray image of dried bone at Z~0 m. The fracture line was not clear, and less informative.

of orthopedics, especially for bone disease. In the future, this novel radiography will be performed at hospitals equipped with a small sized SR ring having an insertion device, like a multi-pole wiggler.

K. Mori (Ibaraki Pref. Univ. of Health Sciences)

References

[1] S. W. Wilkins et al., Nature 384 (1996) 335.
[2] K. Mori et al., Jpn. J. Appl. Phys. 38 (1999) L1339.

9-3. Phase-Contrast X-Ray Imaging using an X-Ray Interferometer for Biomedical Applications

Phase-contrast X-ray imaging using an X-ray interferometer has great potential to reveal the structures inside soft tissues, because about 1000-times higher sensitivity is obtained with this method as compared to the conventional method based on X-ray absorption. Several imaging techniques have been developed to detect the X-ray phase shift, such as an interferometric method using a crystal X-ray interferometer, a Schlieren-like method using crystal diffraction, and a holography-like method. Among these methods, an interferometric method using a crystal X-ray interferometer is the most sensitive method to detect a minute refractive index variation in soft tissue. Phase-contrast X-ray CT has demonstrated rabbit cancer lesions [1] and human cancer lesions [2].

The phase-contrast X-ray imaging system consisted of an asymmetrically cut crystal, a monolithic X-ray interferometer, an object cell and an X-ray CCD camera (Fig. 6). To obtain a large field of view in the phase-contrast X-ray image, a monolithic X-ray interferometer having a field of view with 25 mm × 25 mm was made using a commercially available 10-cm diameter, highly perfect single-crystal silicon ingot [3].

Imaging of the vessel was performed by a physiological saline and compared to the absorption-contrast X-ray image. A rat was anesthetized by pen-

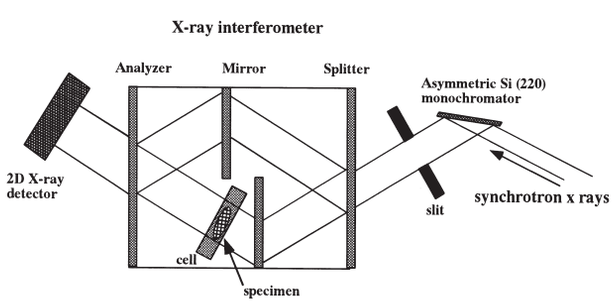

Figure 6.
Schematic drawing of the experiment setup.

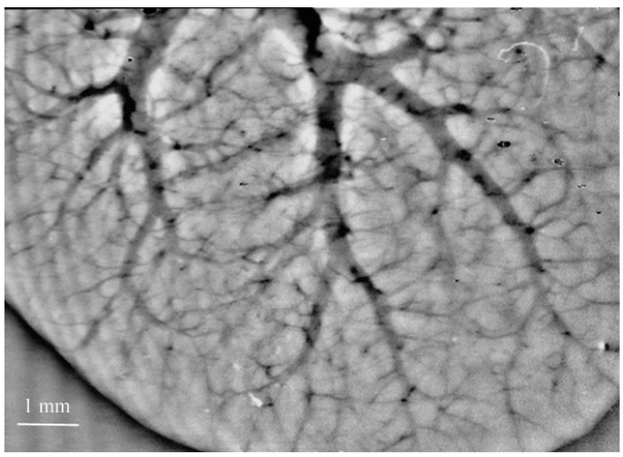

Figure 7.
Phase-contrast X-ray projection image (phase map) of a rat liver filled with physiological saline.

tobarbital, and canulation to the portal vein was performed surgically. The physiological saline was injected from the portal vein and all blood was replaced. After infusion, the portal vein, hepatic artery and hepatic vein were ligated to prevent air contamination. The liver vessels of the rat, minimal diameter of 30 μm, could be clearly revealed in phase-contrast X-ray projection images (phase map) (Fig. 7), whereas the absorption X-ray image could not reveal the vessel at all. The spatial resolution (30 μm) of this image was determined by the diffraction phenomenon within the crystal wafers in the analyzer. The spatial resolution will be improved by using a thin wafer. The X-ray dose used in the phase-contrast X-ray images was about 1/10 for the required X-ray dose to reveal 30 μm in diameter using an iodine contrast material. We are now planning to visualize vessels under *in vivo* condition by using physiological saline.

Y. Itai[1], T. Takeda[1] and A Momose[2] ([1]Univ. of Tsukuba and [2]Univ. of Tokyo)

References

[1] A. Momose, T. Takeda, Y. Itai et al., Nature Medicine 2 (1996) 473.
[2] T. Takeda, A Momose, K. Hirano et al., Radiology 214 (2000) 298.
[3] T. Takeda, A. Momose, Q. Yu et al., J. Synchrotron Rad. 7 (2000) 280.