Medical Imaging with Synchrotron Radiation

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Medical imaging research with Synchrotron Radiation (SR) started in the 80s with first feasibility studies focused on coronary angiography. Contrast agents, generally Iodine-based, opaque to X-rays were used to visualize the heart blood arteries. The main feature of SR exploited for this application was the X-ray beam monochromacity. Indeed, the use of contrast agents takes a huge benefit from the application of the so-called *K-edge digital subtraction imaging*. This technique requires two images taken at two monochromatic X-ray energies, the first just below, the second just above the K-absorption edge of the contrast agent. From the logarithmic subtraction of these images, the visibility of structures perfused by the contrast agent is greatly enhanced and the signals due to other tissues are practically suppressed. With respect to conventional generators, where X-ray spectrum is polychromatic and slightly modifiable, SR monochromatic X-rays make it possible to improve the sensitivity and clinical quality of the images with contrast agents.
Conventional angiography requires the patient catheterization and the arterial injection of contrast agent, with associated risks for the patient. Images with SR were obtained with a less invasive procedure, where contrast agent was administered through an intravenous injection.
First angiographic protocols on patients have been carried out at the SR facilities of Stanford, Brookhaven, DESY and Tsukuba. At ESRF a dedicated end station have been realized for this purpose.
The use of K-edge digital subtraction imaging has been explored also in pre-clinical studies of lungs and brain developed on animal models.
With the development of new hard X-ray imaging beamlines at third generation SR facilities, the application of *phase sensitive* techniques, exploiting the spatial coherence of the source, brought a new impulse to medical imaging with SR.
In conventional radiology carried out with hospital generators the image formation relies on differences in X-ray absorption of the sample. The image contrast, originated by a variation of density, composition or thickness of the sample, is based exclusively on the detection of amplitude variation of the transmitted X-rays. The main limitation of this technique is the poor enhancement of weakly absorbing details in soft tissue.
Phase sensitive techniques are based on the observation of the phase-shifts produced by the sample on the incoming X-ray wave. In general, the phase part becomes important if the source has a high spatial coherence, as it occurs in SR sources.
In the X-ray energy range of 15÷25 keV, the phase shift is up to 1000 times more sensitive to variation of the structure and composition of soft biological tissue when compared to absorption. Therefore it is possible to reveal phase effects even if absorption is very low or negligible.
Different approaches for phase-based radiology, namely the *phase contrast radiography*, the *diffraction enhanced imaging* (or *analyzer based imaging*) and the *X-ray interferometry*, have been implemented and developed at several SR facilities worldwide.
Since the half of 90s these techniques have successfully applied to a variety of bio-medical contexts such as the imaging of soft tissues as in mammography, the study of tendons and cartilages, the imaging of lungs and brain, etc.
In this framework at Elettra the most advanced application is the phase contrast mammography and a dedicated end station for patients imaging is in operation. The first research protocol carried out between 2006 and 2009 aimed at evaluating the diagnostic contribution of mammography with SR in patients with questionable or suspicious breast abnormalities, identified by the combination of

conventional mammography and ultrasounds. Compared with conventional diagnosis, examinations with SR showed mainly a higher specificity, reducing in particular the number of false positives. The talk will give an overview of the SR-based hard X-ray imaging techniques as well as their main applications in medical research.