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X-ray mammography with synchrotron radiation

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For the first time in the literature, radiographs of breast phantoms were obtained using several monochromatic synchrotron radiation x-ray beams of selected energy in the range from 14 to 26 keV. In addition, after optimization of the photon energy as a function of the phantom thickness, several mammographs were obtained on surgically removed human breast specimens containing cancer nodules. Comparison between radiographs using a conventional x-ray unit and those obtained of the same specimens utilizing synchrotron monochromatic beams clearly shows that higher contrast and better resolution can be achieved with synchrotron radiation. These results demonstrate the possibility of obtaining radiographs of excised human breast tissue containing a greater amount of radiological information using synchrotron radiation.

I. INTRODUCTION

Recently, significant advances have been made in x-ray mammography technology, mainly through the use of x-ray tubes with microfocus, molybdenum (Mo) anodes used in connection with Mo filters and high definition screen-filter systems. Nevertheless, it is well known that small breast nodules (in the order of 2–3 mm) cannot be revealed directly by conventional radiographs, but rather may be detected by this method only through indirect means such as microcalcification or structural distortion of the breast texture seen in the radiographic image itself. In order to overcome this difficulty, the use of monochromatic x-ray beams to obtain mammographic images may be suggested. With this in mind, it was the purpose of this study to investigate if very intense monochromatic and quasiparallel x-ray beams coming from synchrotron radiation can produce x-ray mammographs with enhanced contrast and high resolution.

As is well known, previous studies seeking to optimize the mammographic examination (i.e., the highest diagnostic information with the lowest possible dose) revealed the existence of an energy range (16–22 keV, depending upon the breast thickness) capable of optimizing radiographic images by a high signal/noise (S/N) ratio (high contrast) and the lowest dose.[1–3] In addition, recent measurements of the absorption coefficients of normal (fibrous) and neoplastic (infiltrating duct carcinoma) breast tissue using an x-ray tube as source and a high purity germanium crystal as detector show that the difference in the linear attenuation coefficient is 3.5% at 30 keV and 5.3% at 18 keV, respectively.[4] These results suggest the use of lower energy photons in order to obtain a better intrinsically contrasted image. Lower energy intense monochromatic x-ray beams (in the range of 15–25 keV) are available only through synchrotron light. We report here, to our knowledge for the first time in the literature, the first mammographic images of excised human breast tissue using monochromatic synchrotron radiation.

II. INSTRUMENTS AND METHODS

The experimental work was carried out on the x-ray beam line (BX1 Synchrotron Line, Adone Wiggler Programme, Frascati), operating routinely in the 3–30 keV range, connected to a conventional transverse wiggler already in operation at this facility.[5] The apparatus shown in Fig. 1 consists of a Si (111) channel-cut monochromator and two monitors for both incident and transmitted beams. A sample holder, a recording system, and a special device to scan the sample and the recording system in front of the beam is computer controlled so that it is possible to change the scan speed as a function of the desired delivery dose to the sample. In order to study the radiographic signal extraction properties of synchrotron radiation, phantoms made of a solid material (BR12), equivalent to 50% fat and 50% water by weight (ICRU standard composition), were used. A cylindrical detail simulating a cancer growth,[6,7] was embedded in the front side of each phanton and the scanning capability of the apparatus was initially

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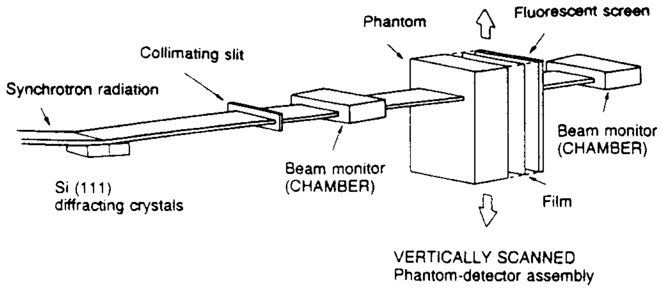


FIG. 1. Schematic drawing of the irradiation equipment used in the experiment.

equal to 50×50 mm^2. To obtain images comparable with those carried out with a conventional mammography unit, the scanning capability was increased to 180×240 mm^2. For a quantitative evaluation of image quality, two different large-area phantoms were used: an RMI detail phantom and a phantom used in the dose and quality in mammography (DQM) Italian survey for mammography optimization.[6] This phantom consists of a Plexiglas bulk ($10\times 10\times 4.6$ cm^3) containing, on the upper side, 15 3-mm-thick and 12-mm-wide wax disks in which three kinds of different details are embedded. More exactly, three quartz microspheres having a diameter ranging from 100 μm to 300 μm diameter, six Al disks having thickness in the range 15–90 μm, and six nylon wires having diameters ranging from 0.33 to 0.7 mm. Finally, for the qualitative evaluation of human breast tissue imaging, various specimens of freshly excised tissue containing cancerous growths were placed in Plexiglas containers filled with isotonic saline solution (Fig. 2). Phantoms and specimens were imaged using both synchrotron radiation and a conventional mammography unit and a 3M screen-film combination. The conventional x-ray source was a MSM-General Medical Mezate 0.1 microfocus apparatus equipped with a Mo rotating anode and a moving grid working from 22 to 35 kVp. The constancy of the processing conditions was monitored. Tissues were provided by the Regina Elena Cancer Institute of Rome and the Institute of Radiology, Tor Vergata University of Rome, which also provided breast specimens having a duct infiltrating carcinoma.

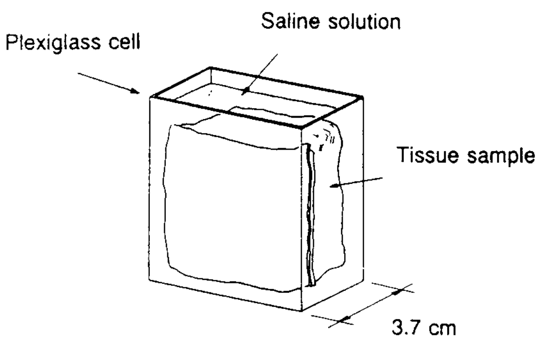


FIG. 2. Sample arrangement used for tissue imaging.

III. RESULTS AND CONCLUSIONS

The information content of the BR12 phantom images was analyzed using an image processor composed of a charge coupled device (CCD) camera and video digitizer connected to a personal computer. The results show an optimal x-ray energy beam for mammography. In fact, the

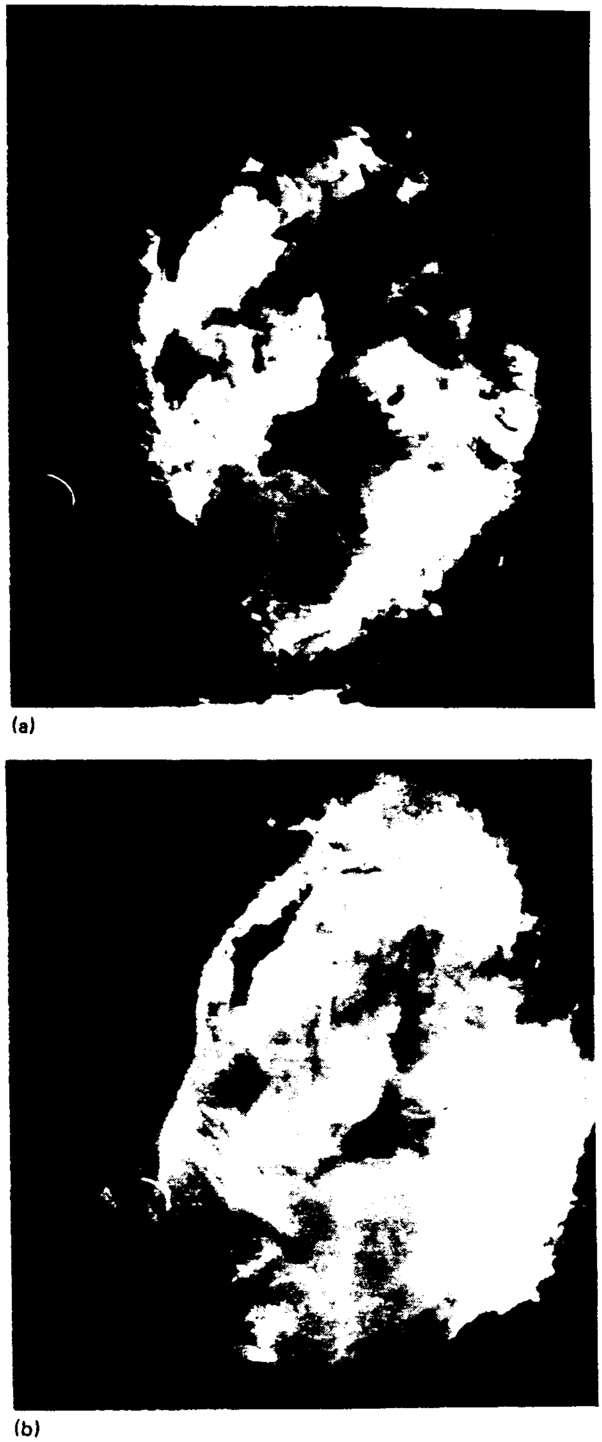
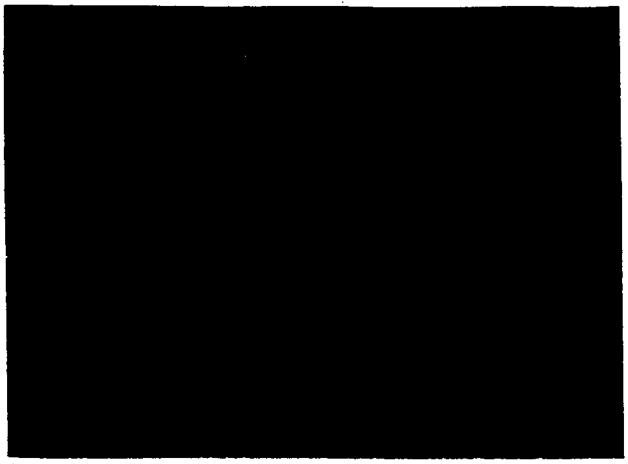


FIG. 3. Mammograms of the same breast tissue specimen containing a cancer nodule made with (a) a 18-keV monochromatic x-ray beam and (b) a conventional mammography unit having a Mo anode, a Mo filter, and operating with an antiscatter grid at 29 kVp. The radiographs have been obtained using a mammographic film-screen system (3M T2/FM) as recording system. These images correspond to an area of about 150 cm^2.



(a) (b)

FIG. 4. Post-processed radiographs of the same breast tissue specimen containing a cancer formation made with (a) a 16-keV monochromatic x-ray beam and (b) a conventional mammography system operating at 27 kVp. The images have been obtained digitizing the radiographs with an image digitizer and submitting them to the same process as contrast enhancement.

$(SNR)^2$ per entrance fluence presents a maximum at 16 keV for a 3-cm-thick phantom and at 19 keV for a 5-cm-thick one. The radiographs of the large-area phantoms show that the contrast of details increases improving the visibility of the smaller details as the energy decreases. However, for phantoms whose thickness is more than 5 cm it is difficult to obtain radiographs using photon energy lower than 16 keV.

With synchrotron light it was possible to detect with certainty 14 of the 15 details contained in the DQM phantom, while with conventional mammographic units it was possible to detect only 12.[8]

In Fig. 3 radiographs of the same breast specimen obtained using both a conventional mammographic unit [Fig. 3(a)] and a 18-keV monochromatic x-ray beam [Fig. 3(b)] are compared. In the synchrotron light image it is possible to observe details and structures not detectable in the conventional one. In fact, various nodules that appear to be uniform in the conventional image clearly show more complex internal structures in the radiograph obtained with synchrotron light, as can be seen in Fig. 4, which presents the post-processed images of a nodule having a diameter of 1 cm.

The dosimetric comparison between the two radiographic techniques has been performed using, as a "figure of merit," the ratio of the energy absorbed by a tissue equivalent phantom (BR12) to the energy absorbed by the intensifying screen.

Assuming that the same energy delivered to the screen yields the same radiographic effect (i.e., optical density), the figure of merit is directly proportional to the absorbed dose. Thus it can be used to compare significantly the two techniques.

As to the images in Fig. 3, obtained with 18-keV synchrotron radiation and a 29-kVp anti-scatter-grid conventional technique "figures of merit" of 31.6 and 39.1, respectively, were obtained assuming a sample transmission equivalent to 4 cm of BR12.

This rough estimate suggests that the doses delivered in the two techniques should be comparable.

In conclusion, the preliminary results presented in this paper clearly show that synchrotron radiation can be used to obtain mammographic images of a higher quality than those obtained by conventional means. These results open the possibility of the design and development of synchrotron mammograph units for the early detection of breast tumors.

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