

Photon Transport in Inhomogeneous Biological Samples

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انتقال الفوتونات في العينات البيولوجية غير المتجانسة

رسالة مقدمة من

وفاء بكر عبد السلام الشرقاوي

الى

قسم الفيزياء الحيوية

كلية العلوم- جامعة القاهرة

للحصول على درجة الماجستير في الفيزياء الحيوية

٢٠٠٩

To
My father,
Mother &
Sister

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Abstract

In the last decade there has been a growing interest in the possibility of characterizing breast cancer using the differences in the coherent x-ray scattering profiles of normal and malignant tissues. To a great extent, characterization has depended on the differences in the peak positions of both tissues in addition to the overall profile, which exhibits a distinctive sharp adipose peak in case of normal breast. In many excised tissue samples, breast cancer samples may be mixed with variable percentage of other tissues, which affects the shape of its x-ray scattering profile and consequently the ability to characterize the tissue. Moreover, fibroglandular tissue produces scattering profile showing an extent of similarity to breast cancer. The present study introduces a Monte Carlo simulation code, which is capable of tracing photon transport inside a mixed two-component sample (inhomogeneous sample). The code makes use of molecular form factor data including molecular interference effects, which are very characteristic for each biological sample. This code is utilized to simulate and best fit x-ray scattering profiles of measured samples.

The fitting process is carried out through calculating the least square error (R^2) and correlation coefficient (c.c.) of measured and simulated data. The accepted constituent percentages are those giving the

smallest possible (R^2) at the maximum possible (c.c.) .This provides reliable breast tissue characterization in addition to quantitative estimate of the percentage of each component in a given sample. Simulation results are performed at energy of 8.047 keV. The investigated samples are beef muscle, beef adipose, normal breast tissue, breast cancer tissue, and water. Results show that, the current Monte Carlo code has successfully reproduced x-ray scattering profiles of single and mixed two-component samples with high precision. It has also offered correct estimate for tissue percentages in mixed samples. It is thus expected that the present simulation would potentially enhance the characterization of breast cancer tissue using x-ray scattering technique. It would also offer a tool for the quantitative estimation of the percentage of breast cancer to normal tissue in a given sample.

1. Introduction:

Scattering of x-ray photons at low energies from biological samples has been a subject of interest over the last few decades. In diagnostic radiology, x-ray scattering causes blurring of images and consequently loss of important diagnostic information. Efforts have been directed towards the evaluation of these effects and the search for methods to reduce such effects.

On the other hand, some researchers found that although x-ray scattered photons represent a problem for radiography, they do hold useful information about the tissue they are scattered from (Speller & Horrocks 1991). As a result, many research groups directed their efforts towards the exploration of the beneficial role of scattered photons in obtaining useful diagnostic information.

In 1978, Dick et al measured the ratio of scattered to total x-ray fluence (scatter fraction) for different combinations of geometrical parameters encountered in diagnostic radiology (x-ray energies of 32 and 69 keV, beam diameters from 4 up to 40 cm, phantom thickness from 5 up to 30 cm and phantom – to – image plane separations from 0.3 up to 0.4 cm). They could also produce simple curves of $\pm 10\%$ estimates of the scatter fraction for the investigated conditions.

Monte Carlo calculations of x- ray scatter data for diagnostic radiology were performed by Kalender 1981. He calculated the scatter intensities relative

to primary intensities for different detectors at various values of object thickness, field size, object – to – detector distance and primary energy. Comparing his results with those of previous investigations, he could resolve contradictions in published measurements regarding the dependence of scatter intensities on primary x-ray energy and detector response.

Chan & Doi 1983 made a detailed description of their Monte Carlo simulation computer program and could verify its validity in the study of scattered radiation in diagnostic radiology. Excellent agreement was obtained between Monte Carlo and experimental results in determining the scatter fractions and edge responses for various phantom sizes, x-ray energies and recording systems.

Bradley and Ghose 1984 studied the scattering of photons in biomedically important elements. They reported that an explicit power dependence of coherent to incoherent scattering on Z (atomic number) might not be easily expressed. They added that Rayleigh scattering is much better represented by the modified form factor rather than the usual form factor approach.

Neitzel et al 1985 investigated the significance of coherently scattered radiation in diagnostic radiographic imaging using a Monte Carlo simulation. Their results for pencil beam geometry indicated that coherent scattering leaving object is almost exclusively single scattering, concentrated near, but not

exactly, at the transmitted primary beam and dominate over multiple incoherent scattering in this region even for thick objects and poly-energetic radiation.

Kosanetzky et al 1987 presented x-ray diffraction measurements for some plastics and several biological samples. They referred to the remarkable difference in the scattering profiles of biological samples in general and fat and water in specific. They suggested a possible use of such difference in image contrast enhancement. They also reported on the calculation of molecular differential scattering cross-section from measured data by fitting with theoretically calculated data at high momentum transfer region where no molecular interference effects are present.

Tartari & Casnati 1989 examined the equivalence in producing coherent and incoherent scattering within a range of variables between biological tissues and some tissue-substitutes accepted by literature. In their conclusions they stated that only a strict equivalence in elemental composition seemed to satisfy simulation in scattering experiments over wide range of irradiation conditions.

Royle and Speller 1991& 1995 used low-angle x-ray scattering to obtain separate responses from bone and marrow tissues for the purpose of bone density measurements. Their results indicated that the usefulness of the method could lie in its ability to focus on a particular region of trabecular bone and to separate the response of the marrow tissue from that of the bone tissue, such that information on the actual trabeculae can be obtained.

A review article in 1991 by Speller and Horrocks reported a wide range of useful applications of photon scattering in medicine and biology. They stated that low-angle x-ray scattering measurements have been used to look at a range of substances from proteins, lipoproteins, natural polymers, synthetic polymers and inorganic substances to aggregations. They added that, since, Compton scattered intensity could be related to electron density or physical density it has had some success in tissue characterization.

Evans et al 1991 presented early photon scattering measurements on breast tissue. They pointed out the expected usefulness of using a monochromatic source for such measurements.

Mooney and speller 1992 used a Monte Carlo simulation program to analyze the effect of multiple scattering on the determination of bone density using photon absorption measurements. Their results indicated that inclusion of scattered radiation in bone density calculations lead up to 3.5% reduction in the estimated values.

Persliden & Carlsson 1997 used a Monte Carlo collision density method to investigate the physical parameters (field area, slab thickness, air gap length and detector type) relevant to the scatter rejection using air gaps in diagnostic radiology. Their results proved that the positional variation of scattered photons in the image plane could be calculated with high resolution and precision.

Westmore et al 1997 described a method for imaging low angle (0° to 10°) x-ray diffraction properties of tissue specimens using a diagnostic x-ray beam and image intensifier-based system. They stated that cross-sections determined from this analysis form the basis of a unique method of characterizing and identifying tissue samples according to their atomic structure rather than x-ray attenuation properties.

Chapman et al 1997 introduced diffraction enhanced imaging as an x-ray radiographic imaging modality using monochromatic x-rays from a synchrotron in order to produce images of thick absorbing objects that are almost completely free of scatter. They concluded that this imaging method might improve image quality for medical applications, industrial radiography for non-destructive testing and x-ray computed tomography.

Farquharson & Speller 1997 measured bone mineral density in archaeological bone using energy dispersive low angle x-ray scattering (LAXS) technique. They concluded that LAXS provides a measured spectrum that contains information which can be used to determine both the bone mineral density and the type of mineral that makes up the bone; a property unique to the LAXS system.

Tartari et al 1997 presented molecular form factors for x-ray coherent scattering in fat and polymethyl methacrylate obtained from measured data. They concluded that the exact knowledge of the angular distribution of photons

scattered in the forward direction was found to be essential in tailoring scattering rejection techniques such as grids or air gaps.

The latter study was followed by useful set of measured molecular coherent scattering form factors of animal tissues, plastics and human breast tissue by Peplow & Verghese 1998. Their data is used in the Monte Carlo simulation presented in this work.

Leclair & Johns 1999 analyzed spectral blur effects in x-ray scatter imaging. They determined the effects of beam polychromaticity on x-ray scatter imaging with the aid of their semi-analytic model that images a target object against a background material of the same dimensions when both are situated within a water phantom. Their conclusion was that the decrease in SNR(signal to noise ratio) due to beam polychromaticity was generally moderate for many x-ray scatter-imaging tasks.

Harding & Schreiber 1999 had discussed a variety of useful applications of coherent x-ray scatter imaging in biomedical science and industry. They pointed out that the development of high power x-ray sources could open the way for novel applications of coherent x-ray scatter imaging.

Elshemey et al 1999 used a Monte Carlo simulation code to examine the possibility of tissue characterization of Lucite, water, fat, muscle and blood. Their code was based on the simulation steps by Chan & Doi 1983. They proposed a transmission geometry where photons traversed the sample and

were detected on the other side. They showed that their simulation was capable of reproducing x-ray scattering profiles measured in reflection geometry as well. They found that energies up to 13 keV and sample thickness of 0.3 cm reported maximum differences between investigated samples.

Kidane et al 1999 introduced a potentially useful x-ray scattering method for the characterization of normal and neoplastic breast tissues. They showed that the abundance of adipose tissue in healthy breast results in a characteristic scattering signature, which was totally different from that of breast carcinoma.

Dilmanian et al 2000 implemented Diffraction Enhanced Imaging in the tomography mode using 22 keV x-rays from Synchrotron Light Source, and imaged a cylindrical acrylic phantom that included oil-filled, slanted channels. The resulting 'refraction CT image' showed the pure image of the out-of-plane gradient of the x-ray index of refraction.

Elshemey et al 2001 studied low-angle x-ray scattering from lyophilized (freeze-dried) whole blood, haemoglobin, serum and red blood cell membranes. They showed that the removal of water by lyophilization from blood and blood constituents yielded characteristic x-ray scattering profiles. They found that the full width at half maximum (FWHM) of the second peak of scattering and the percentage ratio of amplitudes of the first and second peaks (I_1/I_2) % are found to be the parameters most sensitive to irradiation.