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Rayleigh to Compton ratio scatter tomography applied to breast cancer diagnosis: A preliminary computational study

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HIGHLIGHTS

- ► A tomographic technique based on Rayleigh to Compton scattering ratio is proposed in order to study breast tissues.
- ► The Rayleigh to Compton scattering ratio technique is compared with conventional transmission technique.
- ► The influence of experimental parameters (energy, sample, detection system) is studied.

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ABSTRACT

In the present work, a tomographic technique based on Rayleigh to Compton scattering ratio (*R/C*) was studied using computational simulation in order to assess its application to breast cancer diagnosis. In this preliminary study, some parameters that affect the image quality were evaluated, such as: (i) energy beam, (ii) size and glandularity of the breast, and (iii) statistical count noise. The results showed that the *R/C* contrast increases with increasing photon energy and decreases with increasing glandularity of the sample. The statistical noise showed to be a significant parameter, although the quality of the obtained images was acceptable for a considerable range of noise level. The preliminary results suggest that the *R/C* tomographic technique has a potential of being applied as a complementary tool in the breast cancer diagnostic.

1. Introduction

The combination of Rayleigh and Compton scattering through the ratio of their intensities, allow assessing the effective atomic number (Z_{eff}) of the material with which the primary radiation interact (Antoniassi et al., 2011; Cesareo et al., 1992). Particularly, in the study of human tissues, this technique has been used to detect changes in the composition of soft tissues (Puumalainen et al., 1979), liver (Puumalainen et al., 1977), bone (Kerr et al., 1980) and breast (Antoniassi et al., 2011; Ryan and Farquharson, 2010).

An important and promising application of this technique is the possibility of obtaining images which allow obtaining information about the spatial distribution of Z_{eff} in the studied object (Cesareo et al., 2001; Duvauchelle et al., 2000).

In the present work a Rayleigh to Compton ratio (*R/C*) scatter tomographic technique was studied using analytical computational simulation in order to assess its application for breast cancer diagnosis. The influence of various parameters associated to the radiation beam (incident energy), sample (size and tissue glandularity) and detection system (statistical count noise) on the quality of the *R/C* images was evaluated and comparisons with conventional transmission tomographic images were discussed.

2. Materials and method

2.1. Geometrical arrangement of the tomographic simulation

Fig. 1 represents schematically the simulated scatter tomography experiment. The sample (object) is composed of two tissue regions of diameters *D* and *d*: tissue 1 (adipose/glandular) and tissue 2 (carcinoma), this latter representing the presence of a malignant lesion in a breast. It is rotated at uniform angular steps. At each angle the sample is also translated and the scattered signal (projection) at each position is acquired by the scatter

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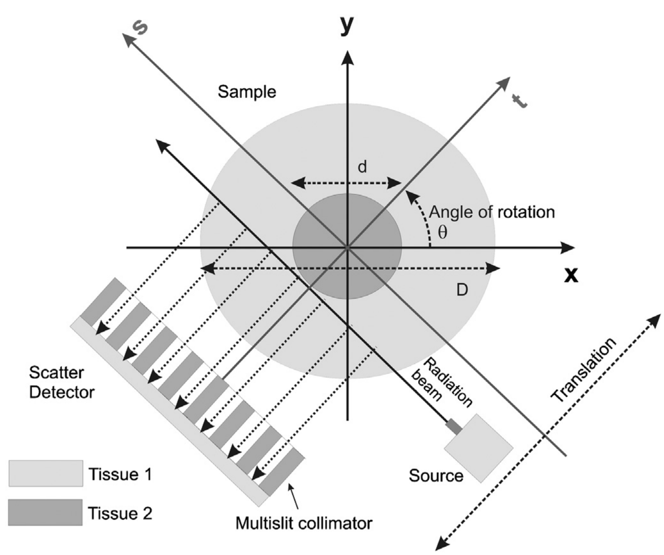

Fig. 1. Scatter tomography arrangement.

detector. The x and y axes are fixed in the reference frame of the sample. The t and s axes are parallel to the translation direction and to the beam, respectively, and they are related to x and y by a rotation of an angle θ. The input dataset is represented by the count rates measured for a complete set of translational and rotational steps.

2.2. Scatter tomography

The number of photons elastically (Rayleigh), N_R, and inelastically (Compton), N_C, scattered by a volume element dV of the sample which is detected by the scatter detector can be written, respectively, in the form (Antoniassi et al., 2011)

$$N_R = N_o\mu_R(x,y)\Delta\Omega_{\text{det}}dV\varepsilon A_R(x,y,\theta) = C\mu_R(x,y)A_R(x,y,\theta)ds, \quad (1)$$

$$N_C = N_o\mu_C(x,y)\Delta\Omega_{\text{det}}dV\varepsilon A_C(x,y,\theta) = C\mu_C(x,y)A_C(x,y,\theta)ds, \quad (2)$$

where N_0 is the number of incident photons per unit area, $\mu_R\,(x,y) = n_{at}F^2\,(x,y)\,(d\sigma/d\Omega)_{Th}$ and $\mu_C\,(x,y) = n_{at}S(x,y)(d\sigma/d\Omega)_{KN}$ are, respectively, the differential linear elastic scattering coefficient and the differential linear inelastic scattering coefficient at the point (x,y) of the sample, where n_{at} is the number of atoms per unit volume ($n_{at} = N_A.\rho/M$, where N_A is the Avogadro's number, ρ is the physical density and M is the atomic weight), F and S are, respectively, the atomic form factor (Hubbell et al., 1975; Schaupp et al., 1983) and the incoherent scattering function (Hubbell et al., 1975), $(d\sigma/d\Omega)_{Th}$ and $(d\sigma/d\Omega)_{KN}$ correspond to the Thomson and Klein–Nishina differential cross-sections, respectively; $\Delta\Omega_{det}$ is the solid angle subtended by the detector, ε is the detector efficiency at the scattering energy and $A_R(x,y,\theta) = \exp(-\int_s \mu_1(x,y)ds) \times \exp(-\int_t \mu_1(x,y)dt)$ is the self-attenuation factor for Rayleigh scattering and $A_C(x,y,\theta) = \exp(-\int_s \mu_1(x,y)ds) \times \exp(-\int_t \mu_2(x,y)dt)$ for the Compton scattering, where the terms of A_R and A_C with integral in ds and dt represent, respectively, the attenuation factor through the paths s, from surface to the elemental scattering volume (dV) in the sample and t, from this element to the surface of the sample in the direction of the detector, μ_1 and μ_2 being the linear attenuation coefficients for incident and inelastic scattered energies, respectively. The right part of Eqs. (1) and (2) is obtained writing dV as $a.ds$, where a is the incident beam area, and grouping the constant terms (N_0, $\Delta\Omega_{det}$, ε and a) in the constant C.

The projections of the elastically (Rayleigh) scattered photons acquired by the scatter detector at each angle of rotation (θ) are obtained summing the contributions of N_R from each volume element of the sample along the incidence line

$$P_\theta(t)_R = C\int \mu_R(x,y)A_R(x,y,\theta)ds, \quad (3)$$

It is possible to use the filtered back-projection algorithm (Shepp and Logan, 1974) to reconstruct the image from the scatter projections (Duvauchelle et al., 2000). The result of the reconstruction gives, instead of the original Rayleigh scattering image $\mu_R(x,y)$, an approximated image $\tilde{I}_R(x,y) = \mu_R(x,y)A_R(x,y)$, altered by the effects of the attenuation of the radiation inside the sample, where $A_R(x,y)$ is an unknown function which is independent of angle θ and the tilde above I represents the operation of filtered back-projection. In an analogous way, the inelastic (Compton) scattering image will be given as $\tilde{I}_C(x,y) = \mu_C(x,y)A_C(x,y)$. The Rayleigh to Compton ratio images $R/C(x,y)$ are obtained through the ratio between $\tilde{I}_R(x,y)$ and $\tilde{I}_C(x,y)$ (Duvauchelle et al., 2000). Considering that the $A_R(x,y)$ and $A_C(x,y)$ terms are roughly equal (since $\mu_1 \approx \mu_2$) and that μ_R and μ_C are both dependent on the atomic number, the $R/C(x,y)$ image allow obtaining information about changes in the spatial distribution of effective atomic number of the studied object (Antoniassi et al., 2011; Ryan and Farquharson, 2010).

2.3. Object (sample) simulation

Computationally, the maps $\mu(x,y)$, $\mu_R(x,y)$ and $\mu_C(x,y)$ were obtained attributing, respectively, values of linear attenuation coefficient, differential linear elastic scattering coefficient and differential linear inelastic scattering coefficient of the breast tissues to each element (or pixel of $\Delta s \times \Delta t$ cm^2) of their correspondent matrices of dimension $n \times n$ ($n = 200$).

The values of μ of the breast tissues for each studied energy were calculated using the program XCOM (Berger et al., 1998). The values of μ_R and μ_C of the tissues were obtained using F and S values calculated using the Independent Atomic Model (IAM) approximation from data table of Schaupp et al. (1983) and Hubbell et al. (1975), respectively. The elemental composition and physical density data were obtained from Woodard and White (1986) for normal adipose breast tissue and from Poletti et al. (2002) for malignant breast tissue.

2.4. Study of the images

The study of the R/C tomographic images was done by assessing the image quality in relation to different parameters of the simulation, associated with the (i) radiation beam (incident energy), (ii) object (size and glandularity of the tissue), and (iii) detection system (statistical count noise).

3. Results and discussion

3.1. Radiation beam: incident energy

Fig. 2 shows the R/C images obtained for two incident energies (17.44 keV and 60 keV) and the intensity profiles along the central line of the reconstructed ($R/C = \tilde{I}_R/\tilde{I}_C$) and real ($R/C = \mu_R/\mu_C$) images.

We can observe from Fig. 2 that the higher incident energy the more the intensity of the reconstructed image approximates to its real value. This behavior is expected because the higher the incident energy, the lower is the attenuation effect inside the sample (Brunetti and Golosio, 2001; Hogan et al., 1991), resulting in $A_R(x,y) \approx A_C(x,y)$.