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Breast tissue contrast-simulating materials using energy-dispersive X-ray diffraction

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ABSTRACT

Breast lesions and normal tissues have different molecular arrangements that affect their diffraction patterns. Different mouldable and non-mouldable materials were analysed using an energy dispersive X-ray diffraction system based on a conventional X-ray source (operated at 70 kVp) and a CdTe detector (Amptek XT-100), including a conventional spectroscopic chain. Combinations of materials were identified to have a contrast comparable to that achieved in diffraction imaging for different breast tissues at the momentum transfer values carrying the greatest amount of information (1.1 nm^{-1} and 1.6 nm^{-1}).

1. Introduction

X-ray diffraction is used to determine the spatial structure of matter at the atomic and molecular level. It is based on the fact that the angular distribution of the number of scattered photons exhibits peaks and that their positions and shape depend on the inter-atomic and molecular structures of the scatterer. Even non-crystalline materials such as tissue have some degree of short range order and so they too can be analysed using X-ray diffraction.

Many studies on X-ray diffraction of biological tissue have shown that adipose tissue has a sharp peak at 1.1 nm^{-1} while tumours have a less sharp peak at 1.6 nm^{-1} (Douglas and Verghese, 1998; Kidane et al., 1999; Poletti et al., 2001). It has been shown that the spectral components carrying most information are centred at 1.1 nm^{-1} and 1.6 nm^{-1}. However the use of the full pattern, rather than of selected momentum transfer windows, would be more reliable in the case of statistically poor data (Pani et al., 2010). Kidane et al. (1999) measured breast tissue scattering properties using an energy dispersive X-ray diffraction system over the momentum transfer range of 0.7–3.5 nm^{-1}. Poletti et al. (2001) calculated form factors for water, adipose, glandular tissue, PMMA, nylon, CIRS 70/30, CIRS 50/50, CIRS 30/70, RMI 454 and polyethylene, while Douglas and Verghese (1998) calculated form factors of lucite, lexan, kapton, water, pork and beef fat, muscle, kidney, liver, pork heart, beef blood, breast tissue and formaline.

Harding et al. (1987) showed how the diffraction pattern for muscle resembles that of water, except in the low momentum transfer region below the main maximum peak at 1.6 nm^{-1}, the scatter value from muscle appearing here to be slightly higher in comparison with water. This probably indicates a greater measure of long-range order in muscle than in water. The diffraction pattern of animal fat shows relatively sharp maxima. This is due to the lipid nature of fat, which results in regularly spaced monolayers of molecules. The orientation of these layers is random when averaged over distances of the order of the primary beam width. Douglas and Verghese (1998) found that the form factors of animal glandular tissue all appear similar in shape to that of water. This depends on the composition of these tissues. Form factors from adipose tissue appear to be very different from water. The adipose tissue from both beef and pork yield form factors that appear to be similar to each other and show some sharp peaks as if from diffraction in crystalline materials.

Collagen fibrils (diameter ~70 nm) in cancerous tissue are unable to aggregate properly to reconstitute the typical bundles found in healthy tissues (Sidhu et al., 2009). The scatter produced by the more amorphous scatter from malignant tissues has been shown to be higher than that of normal tissues (Sidhu et al., 2008).

The aim of the present work seeks to introduce new combinations of materials that simulate the contrast between the various breast tissue types, both healthy and diseased, using X-ray diffraction imaging.

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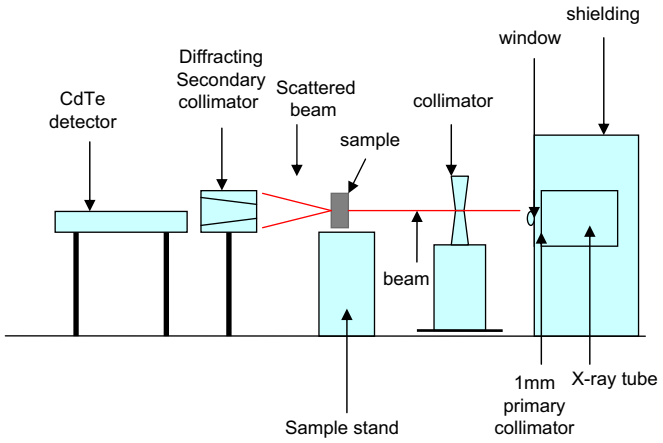

Fig. 1. Experimental setup of the X-ray diffraction system.

Table 1
Contrasts between real tissues.

Contrast calculation between	1.1 nm^{-1}	1.6 nm^{-1}
Adipose and Glandular tissue	0.47	0.29
Adipose and Benign tissue	0.73	0.29
Adipose and Malignant tissue	0.73	0.35
Glandular and Benign tissue	0.24	0.11
Glandular and Malignant tissue	0.24	0.18
Benign and Malignant tissue	0	0.08

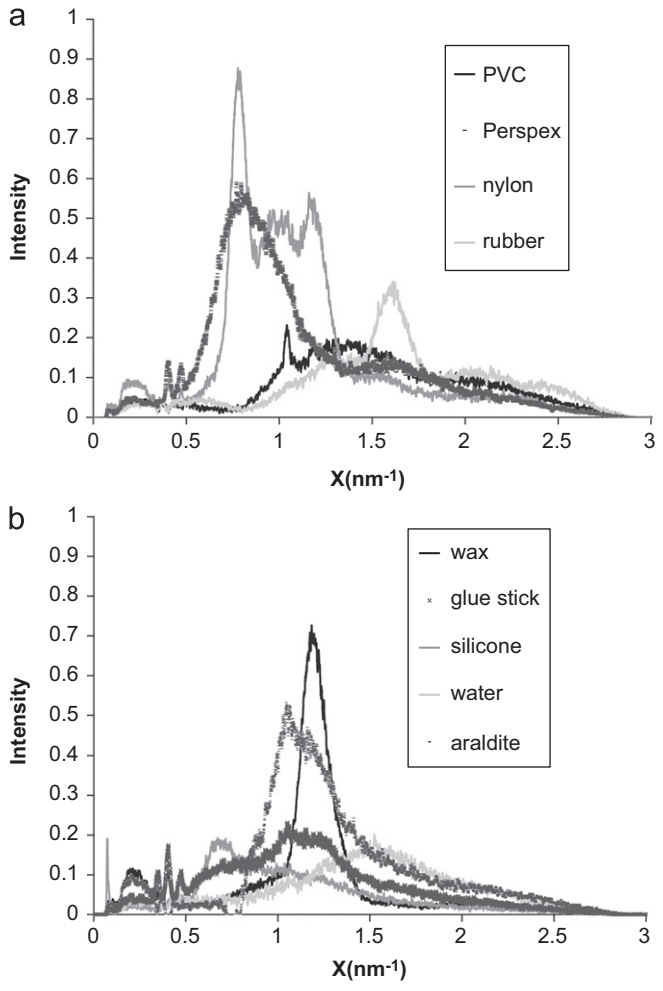

Fig. 2. Diffraction pattern of different used materials.

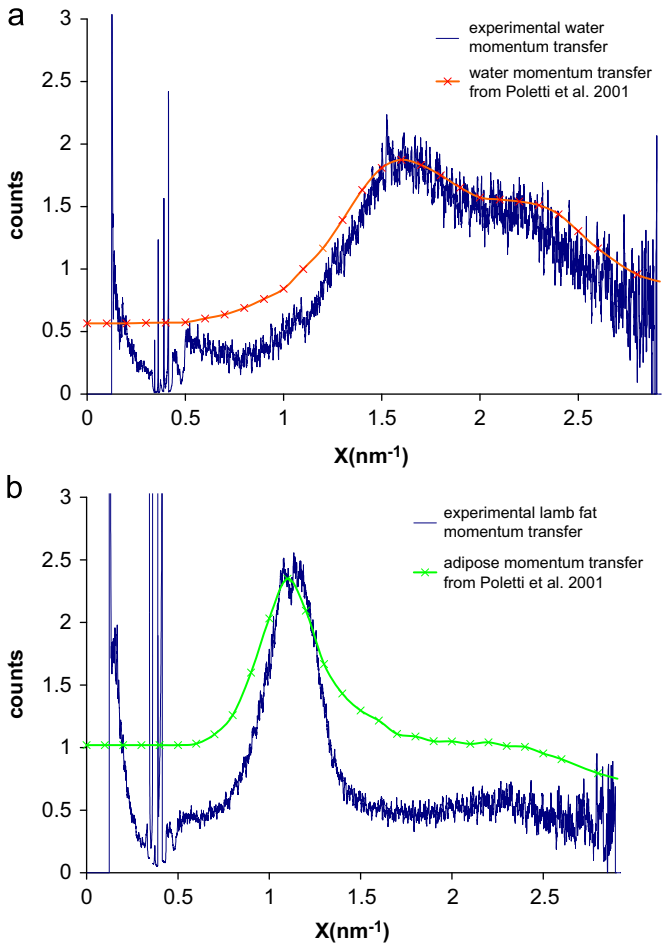

Fig. 3. Comparison of presently measured (a) water and (b) adipose tissue diffraction pattern with that obtained by Poletti et al. (2001). [Note that the discrete features below $x=0.5$ nm^{-1} are due to secondary X-ray fluorescence, i.e. a sample dependent background].

Table 2
Contrast calculations results between different materials at the two significant values of momentum transfer.

Contrast calculation between	at 1.1 nm^{-1}	at 1.6 nm^{-1}
Nylon and Wax	0.37 ± 0.04	0.69 ± 0.07
Nylon and Glue stick	0.54 ± 0.03	0.24 ± 0.05
Nylon and Silicone	0.77 ± 0.04	0.61 ± 0.07
Nylon and Water	0.82 ± 0.04	0.40 ± 0.04
Nylon and Araldite	0.05 ± 0.04	0.34 ± 0.06
Nylon and Rubber	0.82 ± 0.04	0.71 ± 0.02
Nylon and PMMA	0.43 ± 0.03	0.30 ± 0.04
Nylon and PVC	0.69 ± 0.04	0.39 ± 0.07
PMMA and Wax	0.10 ± 0.04	0.78 ± 0.03
PMMA and Glue stick	0.19 ± 0.03	0.46 ± 0.02
PMMA and Silicone	0.59 ± 0.03	0.72 ± 0.04
PMMA and Water	0.68 ± 0.03	0.15 ± 0.03
PMMA and Araldite	0.46 ± 0.04	0.06 ± 0.05
PMMA and Rubber	0.68 ± 0.03	0.59 ± 0.02
PMMA and PVC	0.46 ± 0.03	0.13 ± 0.06
Glue stick and Wax	0.28 ± 0.04	0.59 ± 0.05
Glue stick and Silicone	0.49 ± 0.03	0.48 ± 0.07
Glue stick and Water	0.60 ± 0.03	0.54 ± 0.03
Glue stick and Araldite	0.57 ± 0.04	0.50 ± 0.06
Glue stick and Rubber	0.61 ± 0.04	0.78 ± 0.02
Glue stick and PVC	0.33 ± 0.03	0.53 ± 0.06
Water and Wax	0.71 ± 0.04	0.81 ± 0.04
Water and Silicone	0.22 ± 0.04	0.76 ± 0.04
Water and Araldite	0.83 ± 0.04	0.10 ± 0.05
Water and Rubber	0 ± 0.06	0.52 ± 0.02
Water and PVC	0.41 ± 0.04	0.02 ± 0.06