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Feasibility Study on Pinhole K-shell X-ray Fluorescence Imaging of Gold Nanoparticles

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1. Introduction

As gold nanoparticles (GNP) have been applied to cancer therapy and diagnosis, a real-time *in vivo* quantitative imaging of GNPs are required [1]. One of possible imaging modality is X-ray fluorescence (XRF) imaging. This modality was first proposed in 1986 and synchrotron X-ray was used to invoke atomic relaxation process [2]. Recently, the modality has been developed to be used with polychromatic X-rays so that one can perform an experiment in a laboratory [3]. Comparing with other *in vivo* imaging modalities such as optical fluorescence imaging and photoacoustic imaging, XRF imaging has an advantage for imaging of a deep seated region [3]. Particularly, the principle K-shell XRF of GNPs are 67 and 69 keV which are sufficient to be penetrated through a small mouse. The current study aims to obtain images of GNPs inserted in 3-cm-diam. PMMA phantom with polychromatic X-rays.

2. Methods and Results

2.1 PMMA Phantom and Preparation of GNP Sample

PMMA phantom had 3-cm-diam. and 3-cm-height with a 6-mm-diam. and 3-cm-height hole in it (Fig. 1). 1.9 nm AuroVist™ GNPs (Nanoprobe Inc., US) were used and diluted with deionized water to make concentrations of 0.5, 1.0, 2.0 and 4.0 wt%. GNP samples had inner diameter of 3 mm and outer diameter of 6 mm. The height of GNP solution was 2 cm. The 1-cm-height of top and bottom of GNP sample were filled with PMMA. The samples were inserted in the hole in PMMA phantom one by one.

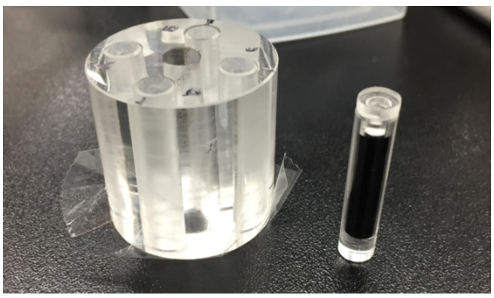

Fig. 1. PMMA phantom and GNP sample.

2.2 Polychromatic X-ray Source

140 kVp with Al, Cu and Sn filter of X-rad 320 (Precision X-ray Inc., US) was used to stimulate an emission of XRF from GNPs. The X-ray machine had an adjustable collimator which could make rectangular radiation fields. However, the field size was controlled by manual and the machine had no digital output for adjusted radiation field size. Therefore, the radiation field size was measured using XR-RV3 radiochromic film as described in Fig. 2(a). This film is usually used for dosimetry of fluoroscopy. The measured radiation field was 1×3 cm^2 as shown in Fig. 2(b).

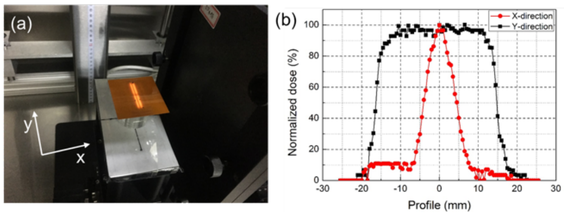

Fig. 2. (a) Photograph of experimental setup for measuring radiation field size and (b) measured radiation field size.

2.3 Detection and Imaging Process

K-shell XRF and Compton scattered photons were measured by developed pinhole X-ray fluorescence imaging system (Fig. 3.) [4]. The system consisted of stage, pinhole collimator, cylindrical tungsten collimator and CZT gamma camera (IDEAS, Norway). Each phantom was irradiated for 5 min with 140 kVp and 15 mA. In order to obtain Compton background, the PMMA phantom filled with 6-mm-diam. and 3-cm-height PMMA column was also irradiated. The XRF images were obtained by subtracting measured counts of the phantom without GNP sample from the counts of the phantom with GNP sample. The energy window was selected to be about 69-71 keV.

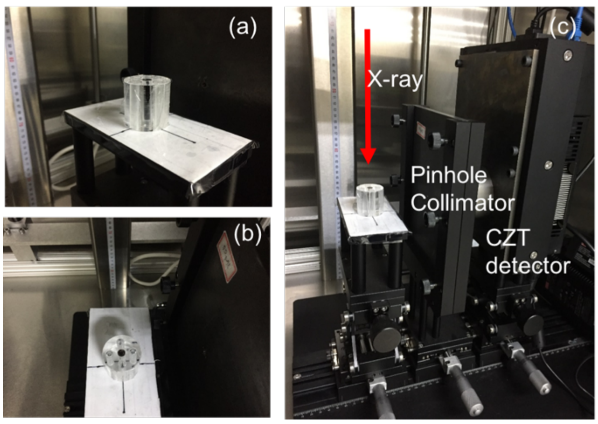

Fig. 3. (a) Lateral view and (b) top view of PMMA phantom inserted with GNP sample. (c) Photograph of pinhole X-ray fluorescence imaging system.

2.4 GNP image

XRF images of GNP samples are shown in Fig. 4. 0.5 wt% GNP sample was clearly discriminated from the background. However, due to the setup difference between the phantom with/without GNP, unexpected high counts were observed as L-shape in Fig. 4(b) and (c).

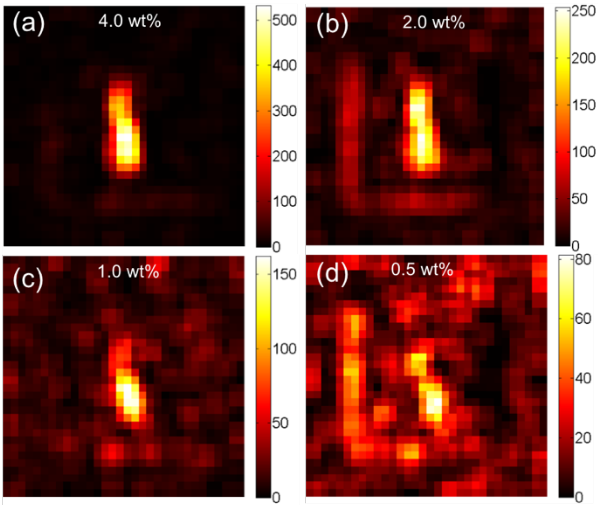

Fig. 4. XRF images of (a) 4.0 wt%, (b) 2.0 wt%, (c) 1.0 wt% and (d) 0.5 wt% of GNP samples.

3. Conclusions

Quantitative images of GNP samples from 0.5 wt% to 4.0 wt% were obtained by the pinhole XRF imaging system. It is necessary to reduce the unexpected noise caused by setup error. Furthermore, several correction factors such as attenuation, sensitivity and pixel non-uniformity is required to be considered. Since the use of pinhole collimator and 2D pixelated could make a direct 2D image with one fan-beam irradiation, image acquisition time was short (i.e., 5 min.) so that the real-time imaging of GNPs is feasible.

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