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Feasibility study of gamma-ray medical radiography

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HIGHLIGHTS

- ► Characterized the performance of gamma-ray radiography.
- ► Displayed medical images of humanoid phantoms using gamma radiography.
- ► Am-241 has the right inherent parameters to be used in diagnostic medical imaging.
- ► Outlined the main advantages and disadvantages of using gamma-radiography.
- ► Production of a pure Am-241 will help in making the exposure times more clinically reasonable.

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ABSTRACT

This research explores the feasibility of using gamma-ray radiography in medical imaging. We will show that gamma-ray medical radiography has the potential to provide alternative diagnostic medical information to X-ray radiography. Approximately one Ci Am-241 radioactive source which emits mono-energetic 59.5 keV gamma rays was used. Several factors that influence the feasibility of this study were tested. They were the radiation source uniformity, image uniformity, and image quality parameters such as contrast, noise, and spatial resolution. In addition, several gamma-ray and X-ray images were acquired using humanoid phantoms. These images were recorded on computed radiography image receptors and displayed on a standard monitor. Visual assessments of these images were then conducted.

The Am-241 radioactive source provided relatively uniform radiation exposure and images. Image noise and image contrast were mainly dependent on the exposure time and source size, whereas spatial resolution was dependent on source size and magnification factor. The gamma-ray humanoid phantom images were of lower quality than the X-ray images mainly due to the low radioactivity used and not enough exposure time. Nevertheless, the gamma-ray images displayed most of the main structures contained in the humanoid phantoms. Higher exposure rates and thus lower exposure times were estimated for different pure Am-241 source sizes that are hypothesized to provide high quality images similar to X-ray images. For instance, a 10 mm source size of pure Am-241 with 7 s exposure time should produce images similar in contrast and noise to X-ray images. This research paves the way for the production and usage of a highly radioactive Am-241 source with the potential to lead to the feasibility of acceptable quality medical gamma-ray radiography.

1. Introduction

Medical images may be formed and constructed by several medical imaging modalities. Each imaging modality provides unique image features. For instance, X-ray planar imaging provides higher spatial resolution than computed tomography (CT) imaging. However, CT images provide a better low contrast resolution (Bushberg et al., 2002). In addition, X-ray image acquisition is fast, easy to use, and may be portable, whereas, CT provides tomography images which allow for the construction of 3D data (Alyassin, 2009; Fournier et al., 2007).

Unlike CT, the magnetic resonance imaging (MRI) modality uses non-ionizing radiation to form medical images that provide an excellent soft tissue contrast (Hendee and Ritenour, 2002). However, MRI requires longer acquisition time, is more expensive, has lower bone and calcification visualizations, and is less

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quantitative than CT (Alyassin, 2009). All these modalities complement each other. Currently there is a revolution in multimodality medical data such as positron-emission-tomography PET and CT, single photon emission computed tomography (SPECT) and CT, X-ray and Ultrasound (US), PET and MRI. Multimodality-data has proven to provide better diagnostic information than an individual medical modality (Kapur et al., 2002; Krug et al., 2010; Liu et al., 2011; Pichler et al., 2008).

In ionizing radiation imaging modalities images may be acquired through transmission or emission scans. X-ray and CT provide transmission scans which mean the X-ray source is located outside the patient and the X-ray field transmitted through the patient records the final image on the image receptor. Unlike CT and X-ray, nuclear medicine (NM) images are formed through an emission scan which means the source of radiation is located inside the patient and the radiation emitted from the source is recorded on the detectors that are located outside the patient. NM imaging mainly provides functional information whereas the transmission scans mainly provide the anatomical information (Raan et al., 2000). The sources of radiation that are used in diagnostic NM imaging are radioactive sources that mainly emit gamma-rays with energies in the diagnostic range (Huda and Slone, 2003; Bushberg et al., 2002).

Radioactive sources have been reported in literature to provide transmission scans to show some anatomical structures. However these scans have either been used for special procedures or with special dedicated detectors. They have not addressed the requirements or the needs of general diagnostic medical imaging procedures with gamma-rays. For instance, some researchers have used gamma-ray scans for attenuation correction in PET (Bailey et al., 2005; Kaplan and Hynor, 1999; Raan et al., 2000). Other researchers have generated beta particle images and gamma-ray images with a special digital probe that was used in radioguided surgery (Tipnis et al., 2004). Some researchers have developed a special radiation-imaging device for imaging with low-intensity gamma-ray sources (Woodring et al., 1999) while others have used gamma-ray imaging with a multiple pinhole imager in NM (Meng et al., 2003).

In addition, much work has been published about industrial gamma-ray radiography (Verbinski and Orphan, 1997). However, the radioactive sources that are typically used in industrial gamma-ray radiography are Cs-137 and Co-60, which emit on the average, high energy photons of 0.662 MeV and 1.25 MeV, respectively (IAEA, 1999). These energies are much higher than the diagnostic energy range. Amercium-241 (Am-241) emits gamma-rays within diagnostic X-ray range (25–150 keV) and has been used in brachytherapy (Muench and Ravinder, 1992; Randinder et al., 1990; Ravinder et al., 1987). It was briefly introduced in producing medical images (AbdulMajid, et al., 2010). Therefore, there is a tremendous lack of testing the feasibility of using the Am-241 radioactive source in producing gamma-ray transmission scans that provide medically diagnostic information.

This research tackles the feasibility of using gammy rays in forming medical images using Am-241 source. Am-241 source emits mono-energetic photons with energies that fall within the diagnostic range. It has also a very long half-life which reduces frequency of replacement of the gamma-ray source. The Am-241 gamma-ray imager should produce medical images with lower dose than the dose delivered by an X-ray machine. It's expected that the patient radiation dose will be lower when using a diagnostic mono-energetic photon beam than when using a poly-energetic photon beam with similar mean energies (Bushberg et al., 2002).

This article first lists the equipment used then describes the methods which consist of some estimated radiation exposure values for Am-241 and many experimental medical image quality tests. Last, it discusses the results of this research and then concludes with the main achievements of this article.

2. Materials

The materials that were used in our research were; an Amercium-241 (Am-241) radioactive source, several 2 mm sheets of lead with different circular size openings, three Kodak computed radiography (CR) image receptors, image quality phantoms, and several humanoid phantoms.

The activity of the Am-241 source at the time of our acquisitions was 0.965 Ci. The diameter of the source that was used to expose and image our objects was roughly 29 mm (see Fig. 1). However, the thickness of the source was not measured because the source was permanently mounted into the source stand. The Am-241 radioactive source emits 35.9% of the time a 59.5 keV and

A B

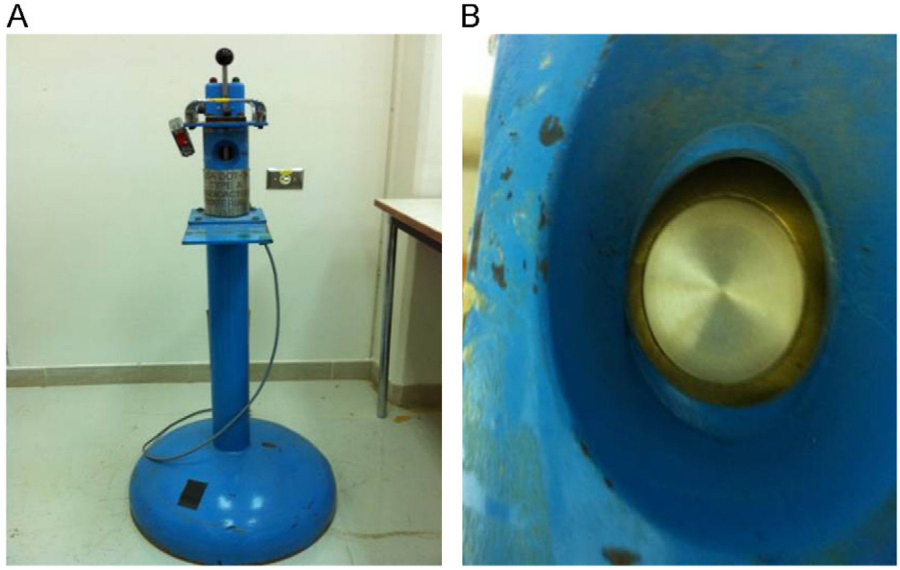

Fig. 1. The Americium-241 radioactive source. Part (A) shows the whole stand and (B) shows a close up view of the source when it is opened.