On the Performance of two Multi-Pinhole SPECT Systems for Small Animal Research

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Abstract— **Molecular imaging calls for imaging systems with both high resolution and high sensitivity. In small-animal SPECT high resolution is typically achieved using pinhole collimation. In order to improve the sensitivity of single-pinhole systems we employ a novel collimation approach called multi-pinhole imaging. This imaging technique extends conventional single-pinhole collimation through the addition of pinholes on each collimator. An important feature of multi-pinhole imaging is the overlap of projections on the detector. This overlap results in a more efficient coverage of the detector and thus a considerable increase in sensitivity. In this contribution we report on the performance of two multi-pinhole imaging systems: a dual-headed Siemens ECAM and a triple-headed Trionix TRIAD. The big-headed ECAM being upgraded with two 10-pinhole collimators, while the medium-sized detectors of the TRIAD were equipped with three 7-pinhole apertures. Image reconstruction is performed using a dedicated OSEM algorithm. Both systems are characterized by a series of phantom measurements and tested on numerous animal studies. We will show that both systems yield excellent image quality with a reconstructed resolution of 1.2mm and a sensitivity of up to 1600cps/MBq. In addition to regular semi-quantitative single-isotope studies, we will present data on dual-isotope imaging, absolute tracer quantification and the fusion of the SPECT images with MR data of the same animal.**

I. Introduction

Pinhole SPECT employing conventional gamma cameras is known to provide high resolution and excellent image quality when the object is small compared to the available detector area. Thus, it can be very useful in pharmaceutical and pre-clinical research where new radio-pharmaceuticals have to be tested in small animal studies. Pinhole SPECT has also become a valuable tool in the emerging field of molecular imaging where small animal imaging experiments are carried out to study biochemical pathways and biological mechanisms or disorders on a more fundamental, i.e. molecular level. However, due to the poor geometric efficiency of the high-resolution collimator the sensitivity in conventional single-pinhole tomography is limited. In order to improve the system sensitivity without degrading spatial resolution we have developed and tested a multi-pinhole collimation technique for high-resolution and high-sensitivity imaging of mice and rats.

This novel collimation technique is an extension of single-pinhole tomography to more than one pinhole per collimator. The pinholes are typically arranged in a way that each pinhole views only a certain part of the object with all pinholes together covering the whole field of view. To accomplish this the pinholes are tilted in the axial and transaxial direction. Another important feature of multi-pinhole imaging is that projections through different pinholes may overlap partially on the detector resulting in a more efficient coverage of the detector area and thus, leading to a considerable increase in system sensitivity. Compared to single-pinhole tomography the multi-pinhole system exhibits a more homogeneous sampling of object space and is less susceptible to inconsistencies arising from incomplete sampling of projection space and the violation of the data sufficiency condition.

In this contribution we report on the performance of two multi-pinhole imaging systems: a dual-headed Siemens ECAM and a triple-headed Trionix TRIAD. The big-headed ECAM being upgraded with two 10-pinhole collimators, while the medium-sized detectors of the TRIAD were equipped with three 7-pinhole apertures. Both systems were characterized by a series of phantom measurements and tested on a variety of animal studies.is project deals with the upgrade of a commercial gamma camera with a dedicated multi-pinhole collimator (Fig. 1) for high-resolution and high-sensitivity single-photon imaging of mice and rats.

II. Materials and Methods

The multi-pinhole collimator designs are based on conventional collimator frames and consist of a 12mm pyramidal lead shielding and an interchangeable multi-pinhole aperture made of 10mm tungsten alloy (HPM1850). The collimator depth, i.e. the distance from the image plane to the aperture plane, totals 140mm. The conical pinholes have an inner diameter of 1 to 2mm and an acceptance angle between 40 to 60° depending on the application. For mouse studies both systems are operated at a radius of rotation of 30 to 35mm with corresponding magnifications between 4.7 and 4. A rat is typically measured at a ROR of 40 to 45mm yielding magnification values between 3.5 and 3.1. The overlap fraction in the multi-pinhole projections typically ranges from 40 to 60%.

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High-resolution pinhole imaging requires the exact knowledge of the geometrical imaging parameters, i.e. the collimator depth, the radius of rotation, the center of rotation shift, and the aperture offset in the axial and the transaxial direction. In order to determine these parameters we have developed a calibration method based on the SPECT acquisition of a three-point source phantom. This calibration estimates the geometric parameters to within ±0.2mm and is typically repeated every 6 to 12 month.

The tomographical image reconstruction is carried out using a dedicated multi-pinhole algorithm. This iterative reconstruction is based on the maximum likelihood approach that solves the set of linear equations connecting the unknown activity distribution with the measured projections. The entries of the system matrix are pre-calculated numerically using a dedicated ray-tracing technique, thus, physical effects such as aperture penetration at the pinhole edges or varying photon transmission and absorption at different angles of incidence are incorporated in the system model. To speed up the reconstruction we have implemented the method of ordered subsets. The reconstruction is controlled by a robust and easy-to-use graphical interface and is integrated into the clinical network environment via DICOM and Interfile data exchange.

III. Results and Discussion

The imaging capabilities of the two multi-pinhole imagers were tested thoroughly on measured phantom and animal data. It was found that both systems yield excellent image quality with a reconstructed resolution of 1.2mm (see Fig. 1) and an average sensitivity of up to 1600cps/MBq. Depending on the tracer used in the mouse studies small anatomical details such as 2mm tumors, cortex versus medulla of the kidneys, the mouse striatum or small bone structures were clearly resolved. Even at very low doses (< 50µCi) and poor counting statistics (< 5kcts/view) the multi-pinhole systems provided remarkably good image quality. The acquisition time for a complete SPECT study ranges from 5 to 15min. while the reconstruction times vary from 10 to 15min. depending on the number of pinholes per collimator.

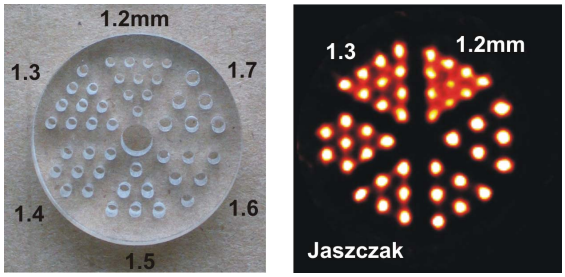

Fig. 1. Multi-pinhole SPECT of a miniature Jaszczak phantom. Pinhole diameter 1.5mm.

We have also investigated the possibility of performing dual-isotope imaging with Tc-99m and In-111. Both isotopes are imaged simultaneously and their corresponding activity distributions are separated using energy discrimination. Further, as many imaging applications require the knowledge of the absolute tracer concentrations (µCi/ml) we have studied quantification capabilities of our multi-pinhole imagers. It was found that absolute activity quantification in small animals is feasible and that the error typically amounts to less than 3%. Finally, we have investigated the fusing of high-resolution SPECT data with MR images of the same animal. The MR data was acquired on a clinical 1 Tesla MR system using a miniature receive-only RF coil and a double-echo imaging sequence. Image fusion was carried out by a semi-automatic procedure employing a mutual information algorithm (see Fig. 2).

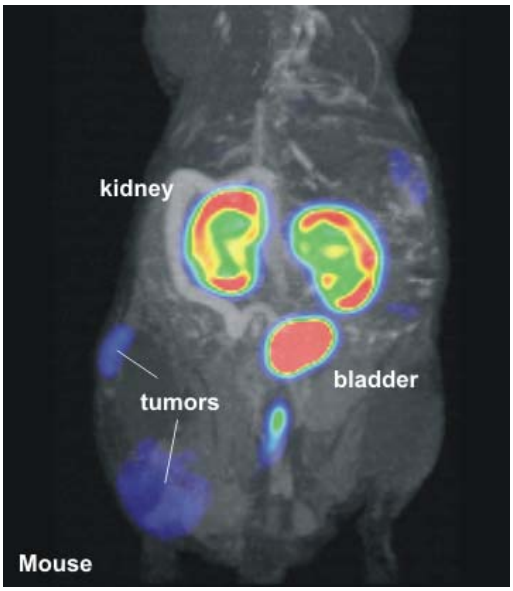

Fig. 2. Fusion of a mouse tumor study with MR data of the same animal. Pinhole diameter 1.5mm.