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An axis of rotation alignment system for high-resolution pinhole SPECT imaging

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Abstract

We developed a simple geometric calibration method for modified animal pinhole single photon emission computed tomography (SPECT) imaging systems using a laser alignment system that does not require additional calibration scans, and verified the feasibility of this system. An optical system consisting of a laser generator and a reflecting mirror, and an alignment method using this system were developed. After laser alignment had been completed, SPECT scans of a Tc-99m line source were performed. After acquiring data with complete alignment, the rotation stage was moved along the y-axis (parallel to the detector plane) to acquire off-axis data. Using these on- and off-axis settings, a micro-performance phantom with hot-rod inserts was scanned after filling with Tc-99m solution. Reconstructed images of the line source and the hot-rod phantom showed that image degradation was minimized when the rotation center was completely aligned using our system. The spatial resolution of the reconstructed image measured using the line source was finest under complete alignment. Under this condition, the smallest hot rod (1.2 mm diameter) was resolved in the SPECT image acquired using a 0.5 mm pinhole aperture. The effects of misalignment were clearly observable in off-axis images; only hot rods with more than 3.2 mm diameter were resolved in 1 mm off-axis image whereas there were no resolvable hot rods with more than 2 mm off-axis image. This system of which the feasibility was verified in the present study will be useful for low-cost molecular imaging studies using single photon emitting tracers.
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1. Introduction

Single photon emission computed tomography (SPECT) imaging with a pinhole collimator is a powerful molecular imaging research tool because it provides information on the spatial and temporal distributions of single photon emitting molecular imaging probes at a spatial resolution that is high enough for small animal (usually rodents) studies [1–5].

It is also possible to improve photon collection efficiency (sensitivity) using multiple gamma-ray detectors and pinhole apertures [4,6–8]. Although the merits of these multi-pinhole SPECT imaging methods are evident, it should also be noted that expensive dedicated animal SPECT systems, or alternatively, multi-pinhole collimators are required for this advanced imaging technique. Therefore, modified animal SPECT imaging systems based on a clinical gamma camera and smaller pinhole apertures than

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those used clinically are still regarded as a practical alternative to dedicated imaging units [4,8–10].

One of the obstacles concerning the use of clinical gamma camera systems for this purpose is that usually only one pinhole collimator is available, because the pinhole collimator is commonly used for unidirectional planar imaging of the thyroid or skeletal joints, but pinhole SPECT is rarely performed in the clinical environment. The rotation of a single detector or unbalanced multiple detectors, due to the availability of only one pinhole collimator, results in serious angle-dependent fluctuations in the distance of the detector from the center because of the gravitational effect of the mass of the detector and the collimator [5,8,11,16].

Thus, the rotation of objects in front of the fixed detector head might provide a practical solution in such situations reducing the so-called 'center of rotation (COR) error'. In the strategy of rotating object, however, misalignment between the ideal axis of rotation and the center of the rotating stage (Fig. 1) can cause another type of COR error [10,12–14]. The effect of this misalignment is illustrated using mathematical phantom data in Fig. 2. After an intentional shift of the center of rotation, three point sources were projected for each rotation angle to generate a sinogram. In the sinogram, we can identify offsets in the trajectories of the point sources from the center over all the projection angles (Fig. 2A). A reconstructed image of this sinogram shows significant distortion of the object: the points are reconstructed as donuts in Fig. 2B.

In this study, we developed a laser alignment system that provides a convenient and efficient solution for misalignment errors, and we tested the feasibility of this system using a line source and cylindrical phantom data.

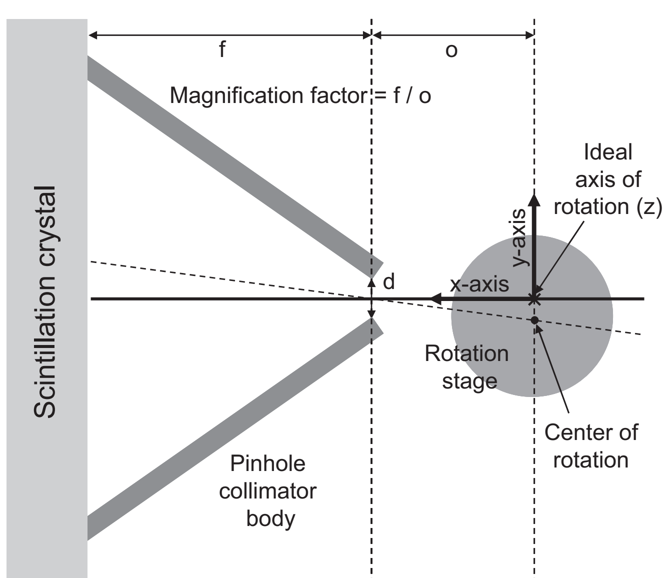

Fig. 1. Geometry of pinhole SPECT imaging with a stationary camera and a rotating object.

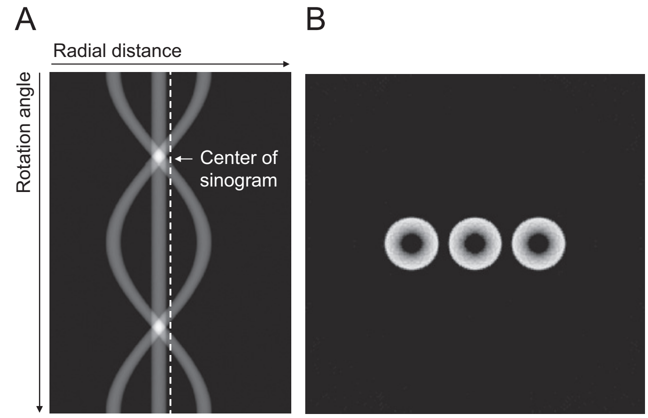

Fig. 2. Effects of positioning errors due to mismatches between the ideal axis of rotation and the center of rotation: (A) simulated sinogram of three point sources with such a mismatch, (B) reconstructed image of the point sources.

Table 1
Specifications of the Phillips Skylight SPECT system

Description	Type or dimenxsion
Non-Anger digital detector	1 ADC/PMT
Field of view	38.1 cm × 50.8 cm (15″ × 20″)
Crystal material	NaI(Tl)
Crystal thickness	9.5 mm (3/8″)
Photomultiplier tubes/head	55

2. Materials and methods

2.1. SPECT system with a pinhole collimator

For the pinhole SPECT studies, a Skylight dual-head SPECT system (Phillips Medical System, Cleveland, OH, USA) was used. The specification of this system is shown in Table 1. The detector head of this system was equipped with a pinhole collimator. Although the size of the full field-of-view (FOV) was 381 cm × 50.8 cm (15″ × 20″), only a central FOV of 25.4 cm × 25.4 cm (10″ × 10″) was used for pinhole imaging because of the restricted collimator geometry.

The pinhole collimator consists of a main body and a replaceable aperture (Fig. 3). Pinhole apertures provided by the manufacturer for the clinical purposes have hole diameters of >3.0 mm to achieve sufficient system sensitivity. However, the spatial resolutions possible at these apertures are not suitable for small-animal imaging. Thus we manufactured pinhole apertures with smaller hole diameters of 0.5, 1.0 and 2.0 mm to improve the spatial resolution (Precise Corporation, Caryville, TN, USA). The distance from the pinhole to the crystal surface was 17.8 cm (7″) and the cone angle of the pinhole main body was 70°.

2.2. Object rotation stage and laser alignment system

A rotation stage driven by a step motor and computer control program (to control the rotation angle and time

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