The Design and Manufacture of an Annular Variable-Focusing Collimator for Highsensitivity Brain SPECT

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***Abstract*—Sensitivity near the center of the brain is critical for some clinical applications of brain SPECT, especially for those applications which require dynamic imaging. We have designed and built a novel collimator for the CeraSPECT dedicated brain SPECT system which uses variable focusing to increase the sensitivity for central regions of its field of view. The sensitivity at the center of the field of view is increased by a factor of two compared to the standard three-segment parallel-hole collimator; this sensitivity gain is achieved without compromising spatial resolution.**

***Index Terms*—Annular brain SPECT, CeraSPECT, SensOgrade collimator, variable-focusing collimator.**

I. Introduction

SENSITIVITY in the central region of the brain is important for a number of clinical applications of brain SPECT imaging. Perfusion imaging of central structures can be useful in early diagnosis of Alzheimer disease [1]. Striatal imaging, using various tracers of neurotransmitter function, has been used to study Parkinson disease [2]–[8], Huntington disease [9], and attention deficit hyperactivity disorder (ADHD) [10]. Some of these clinical applications require quantitative estimates extracted from a series of rapidly acquired dynamic frames. High sensitivity is particularly important for such dynamic studies, as it is not possible to compensate for low sensitivity by increasing imaging time. Furthermore, we have previously shown by simulations studies that for certain estimation tasks the expected linear relationship between parameter estimation variance and pixel variance breaks down at noise levels above a certain task-dependent threshold. Estimation of kinetic parameters falls into the category of tasks affected by this phenomenon, which can occur even at count levels considered clinically acceptable [11], [12].

Because of photon attenuation in the brain, the overall statistical noise at the center of SPECT brain images is greater than at the periphery for standard, uniform-sensitivity collimators. For conventional rotating SPECT cameras, one way to increase the number of photons detected is to use fan-beam or cone-beam focusing collimators [13]–[16]. Even higher sensitivity has been achieved by using an astigmatic converging collimator [17] or by decreasing focal length and placing the collimator as close to the brain as possible while keeping the field of view (FOV) large enough to encompass the entire brain [18]–[21]. For annular SPECT camera, raising sensitivity by using variable-focusing collimator has never been explored although Hattori *et al.* was the first to propose using a continuous collimator by varying the angulations of the collimator to achieve uniform sensitivity [22].

We have previously shown theoretically that a collimator with a centrally peaked sensitivity function, i.e., one that collects more photons from its projections through central regions of transaxial plane than from outer regions, yields higher sensitivity than does a uniform-sensitivity collimator [23]. The newly designed annular variable-focusing collimator, SensOgrade, achieves a centrally peaked sensitivity function by sampling more heavily in (i.e., detecting more photons from) the central regions. Replacing the standard CeraSPECT three-segment parallel-hole collimator with the newly designed collimator would significantly increase sensitivity at the center of the brain without compromising sensitivity at the periphery of the FOV.

The CeraSPECT system offers significant advantages over conventional cameras for dedicated brain imaging [24], [25]. The CeraSPECT uses a single continuous cylindrical sodium-iodide (NaI(Tl)) annular crystal and a three-segment parallel-hole collimator (Fig. 1). The crystal is stationary; the collimator rotates within it. At a given angular position, three parallel-hole projections, at 120 degree intervals, are acquired simultaneously. The stationary design of CeraSPECT makes the system stable and uniform, and eliminates the cost associated with detector rotation. More importantly, its 2π coverage leads to sensitivity higher than that of dual-head systems and similar to that of triple-head systems. We have previously shown that the CeraSPECT system equipped with the standard three-segment parallel-hole collimator can, potentially, yield higher performance than can a conventional dual-head SPECT system in tasks related to early diagnosis of Parkinson disease [26]. In this paper, we present the design and manufacturing process of the SensOgrade collimator, and determine, using Monte Carlo simulated and experimentally acquired phantom data, the sensitivity improvements from such a collimator. Like the standard parallel-hole collimator, the SensOgrade collimator rotates within the crystal during data acquisition.

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Representative Results:

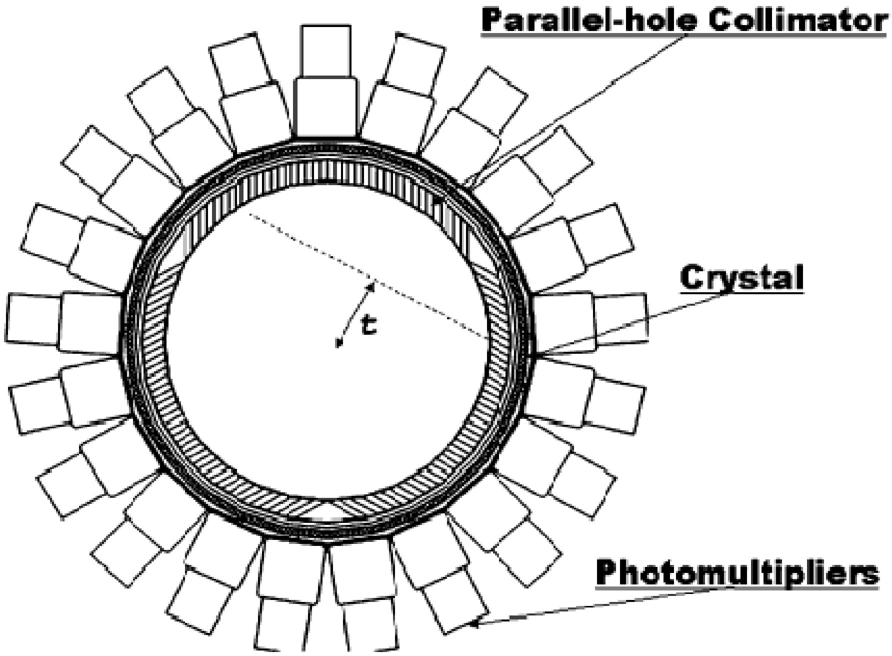

Fig. 1. Schematic illustration of CeraSPECT camera equipped with a three-segment parallel-hole collimator.

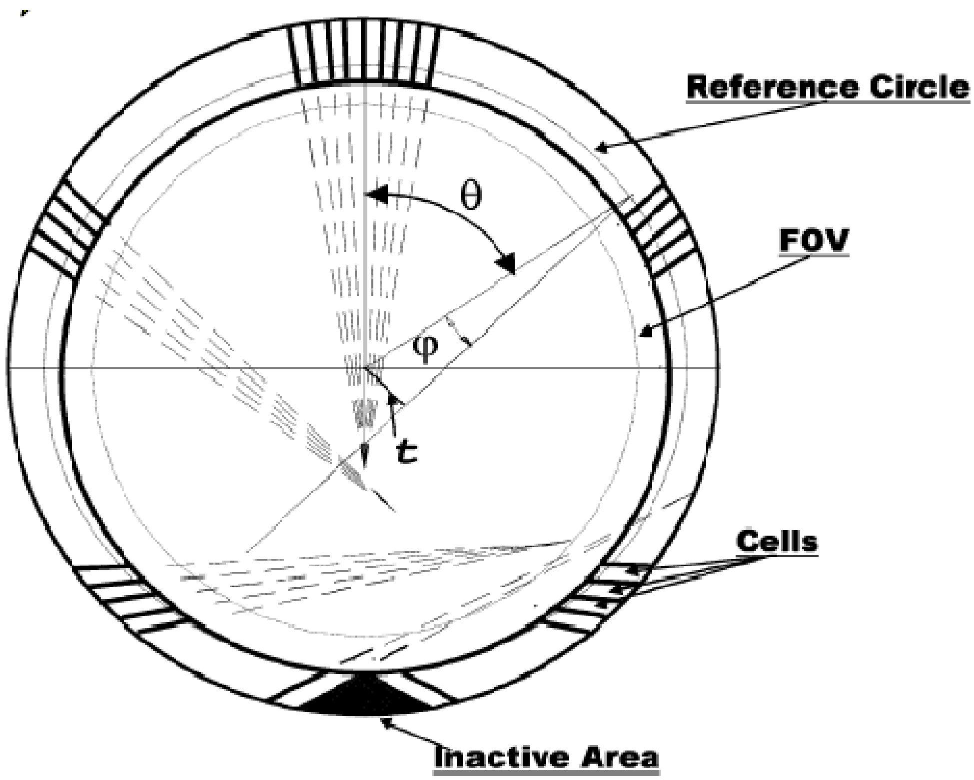

Fig. 2. Schematic illustration of the SensOgrade collimator. The collimator holes extend between two nonconcentric circles. All collimator holes are spaced equally on the reference circle. is the transaxial distance, which is the distance between the center and the corresponding projection line, is the angle between the vertical line and radial direction, and is the angle between radial direction and projection line.

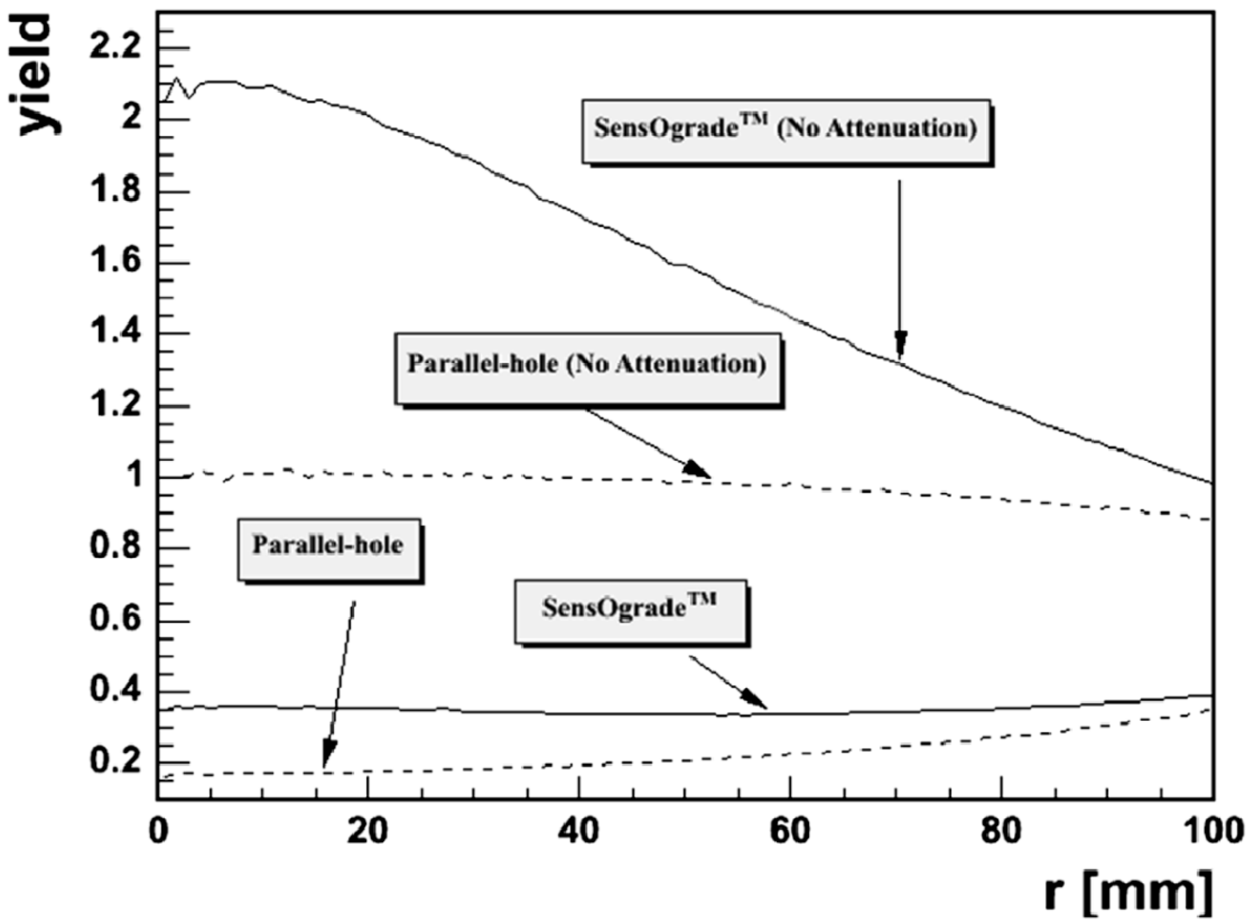

Fig. 6. Sensitivity versus distance from the CFOV for both the three-segment parallel-hole and SensOgrade collimators, obtained from a simulated image of a cylindrical water phantom of 236 mm in diameter. The sensitivity given here is proportional to number of unblocked photons (normalized to the number of photons generated) per unit image volume. The sensitivity for the three-segment parallel-hole collimator at r=0, which is 2.3 unblocked photons per 10 000 generated photons, is scaled to 1.

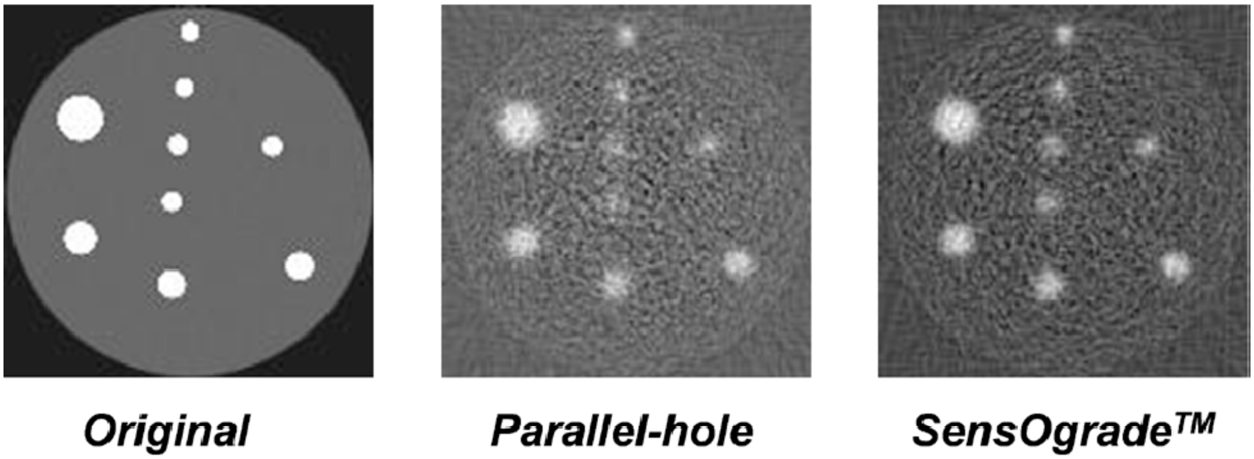

Fig. 7. Original image used to generate simulated data and images reconstructed by filtered backprojection from projection data generated assuming the three-segment parallel-hole and SensOgrade collimators.