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A High-Resolution Imaging Technique using a Whole-body, Research Photon Counting Detector CT System

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Abstract

A high-resolution (HR) data collection mode has been introduced to the whole-body, research photon-counting-detector CT system installed in our laboratory. In this mode, 64 rows of 0.45 mm $\times$ 0.45 mm detectors pixels were used, which corresponded to a pixel size of 0.225 mm $\times$ 0.225 mm at the iso-center. Spatial resolution of this HR mode was quantified by measuring the MTF from a scan of a 50 micron wire phantom. An anthropomorphic lung phantom, cadaveric swine lung, temporal bone and heart specimens were scanned using the HR mode, and image quality was subjectively assessed by two experienced radiologists. Comparison of the HR mode images against their energy integrating system (EID) equivalents using comb filters was also performed. High spatial resolution of the HR mode was evidenced by the MTF measurement, with 15 lp/cm and 20 lp/cm at 10% and 2% MTF. Images from anthropomorphic phantom and cadaveric specimens showed clear delineation of small structures, such as lung vessels, lung nodules, temporal bone structures, and coronary arteries. Temporal bone images showed critical anatomy (i.e. stapes superstructure) that was clearly visible in the PCD system but hardly visible with the EID system. These results demonstrated the potential application of this imaging mode in lung, temporal bone, and vascular imaging. Other clinical applications that require high spatial resolution, such as musculoskeletal imaging, may also benefit from this high resolution mode.

Keywords

Computed tomography (CT); spatial resolution; photon counting detector (PCD)

Purpose

The purpose of study was to evaluate a new high-resolution (HR) imaging technique available on our research photon-counting-detector (PCD)-based CT system by quantitatively assessing image quality and demonstrating potential clinical applications using phantoms and cadaveric specimens.

Methods and Materials

A whole-body research PCD-based CT scanner has been installed in our lab, which was developed using a dual-source CT system platform with one x-ray source coupled to an energy integrating detector (EID) and the other to a PCD [1–4]. The native detector pixel size is 0.225 mm by 0.225 mm for the PCD system. However, the system is usually operated using macro pixels (0.9 mm by 0.9 mm) by grouping 4 by 4 native detector cells. The PCD system is capable of acquiring energy selective data with either 2 or 4 energy thresholds, consequently yielding 2 or 4 energy bins. Detailed descriptions of the system can be found elsewhere [1–4]. Previous studies using the system demonstrated that the PCD system was capable of providing clinical image quality at clinically realistic levels of x-ray photon flux compared to a commercial EID system [5].

Some clinical applications, such as lung, vascular and temporal bone imaging, require high spatial resolution to delineate small anatomy and pathology. This requires very high resolution CT imaging techniques. Recently, a high-resolution mode was implemented on the PCD subsystem of the prototype scanner. In this mode, instead of grouping 4 by 4 detector cells together to form the 0.9 mm by 0.9 mm macro pixel, it reduced the pixel size by half, i.e. grouping 2 by 2 native detector cells (Figure 1). This mode used 64 detector rows, each containing 960 pixels of size 0.45 mm by 0.45 mm, which corresponds to 0.25 mm by 0.25 mm at the iso-center. Due to the increased amount of data (4 times of that in macro mode), only one energy threshold was available for testing for each pixel in the modes' current implementation.

To evaluate system performance and to demonstrate its potential clinical applications, we performed a series of experiments using physical phantoms and cadaveric specimens. Image resolution was assessed in terms of MTF measurement by scanning a 50 μ m diameter tungsten wire. An anthropomorphic lung phantom (LUNGMAN, Japan), together with lung nodules of different sizes and shapes was scanned to evaluate the impact of high resolution on lung imaging. In addition, cadaveric specimens, including a swine lung, a swine heart, and a human temporal bone (Figure 2), were scanned to evaluate image quality and to demonstrate the potential clinical applications of the HR mode in different clinical arenas. The phantoms and specimens were scanned at 120 kV, the most commonly used tube potential in clinical practice, while using an energy threshold of 25 keV for all experiments. Tube current and rotation time product was between 120 to 300 mAs, depending on the phantom. Four consecutive axial acquisitions were conducted. All images were reconstructed with a sharp kernel (S80) and 0.25 mm slice thickness. Two radiologists (each with over 15 years of experience) subjectively reviewed images from the anthropomorphic phantom and cadaveric specimens, focusing on image quality and potential clinical impact.

The temporal bone specimen was also scanned on an EID system, using a commercial high resolution mode that was achieved by using comb filters in front of the detector [6]. Scan was performed at 120 kV and 280 mAs. As the blocked photons would have already passed through the patient and contributed to patient dose, the comb-filter-based HR mode on the EID system achieves high resolution with the penalty of lower dose efficiency. This penalty, however, didn't exist for the PCD system using the smaller detector pixels, as all photons are

detected by the smaller detector pixel. Image quality of the cadaveric temporal bone specimen was compared between the EID and PCD systems.

Results

Figure 3 shows the MTF curve of the PCD HR mode, which demonstrates the resolution available with the PCD HR mode (the 10% and 2% MTF values were at 15 and 20 lp/cm, respectively). Figure 4 shows images of the anthropomorphic lung phantom. Small lung vessels and lung nodule inserts were clearly delineated in these images. Figure 5 shows sample images of the swine cadaveric lung, human cadaveric temporal bone, and swine heart specimen. In Figure 5a, interlobular septa and centrilobular ground-glass opacities surrounding small airways are clearly visible in the lung specimen image, especially within the dependent portions of the upper lobe. Figure 5b shows the fine structures of the temporal bone, with the 'ice cream cone' structure (malleus head and incus body) clearly visualized. Figure 5c shows a volume rendering image of the heart specimen with vessels filled with lead Microfill. Transmural coronary arteries, which are far less than 1mm in diameter, are clearly visible in the volume rendering image.

Figure 6 shows the MTF curves for the high resolution mode on PCD and the high resolution mode on commercial EID achieved by using comb filters in front of the detectors. Although slight shape difference was observed, the overall in-plane resolution (10% or 2% MTF) was similar between the two systems. Figure 7 shows images of the same temporal bone scanned using the EID and PCD systems. The PCD image (right) shows clear delineation of the stapes superstructure (arrow) that is hardly visible in images from EID system (left). This is mainly due to the high spatial resolution, especially the increased z-resolution, using the PCD system (0.25 mm) compared to that of EID system (0.4 mm).

New or breakthrough work to be presented

This is the first high-resolution imaging assessment on a PCD-based CT scanner, which could have substantial impact on clinical applications requiring high spatial resolution, such as lung, vascular, temporal bone, and musculoskeletal imaging.

Conclusions

In this study, we have presented an high-resolution imaging mode on a PCD-based CT scanner, with pixel size of 0.25 mm by 0.25 mm. MTF measurements using a thin wire showed spatial resolutions up to 20 lp/cm at 2% MTF using this mode. This improvement in resolution was achieved without the use of a dedicated HR grid and in a much more dose efficient manner. Studies using anthropomorphic phantoms and cadaveric specimens demonstrated the potential application of this imaging mode in lung, temporal bone, and vascular imaging. Other clinical applications that require high spatial resolution, such as musculoskeletal imaging, may also benefit from this high resolution mode.

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Figure 1.
Native pixel (blue) and HR pixel (red) of PCD detector.

Figure 2.
Left to right: Cadaveric swine lung within chest phantom, heart and temporal bone specimens were imaged using the ultra-high-resolution scanning mode.

Figure 3.
MTF of the HR mode.

Figure 4. Images of the anthropomorphic lung phantom showing clear delineation of small lung vessels (left) and the star-shape lung nodule (right).

Figure 5.
Images of the swine lung (a), cadaveric temporal bone (b), and heart specimens (c).

Figure 6.
MTF of EID and PCD systems.

Figure 7.

The HR image from PCD system (right) showed clear delineation of the stapes superstructure (arrow) that was hardly visible in image from EID system (left).