Comparison of a Photon-Counting-Detector CT with an Energy-Integrating-Detector CT for Temporal Bone Imaging: A Cadaveric Study

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ABSTRACT

BACKGROUND AND PURPOSE: Evaluating abnormalities of the temporal bone requires high-spatial-resolution CT imaging. Our aim was to assess the performance of photon-counting-detector ultra-high-resolution acquisitions for temporal bone imaging and compare the results with those of energy-integrating-detector ultra-high-resolution acquisitions.

MATERIALS AND METHODS: Phantom studies were conducted to quantify spatial resolution of the ultra-high-resolution mode on a prototype photon-counting-detector CT scanner and an energy-integrating-detector CT scanner that uses a comb filter. Ten cadaveric temporal bones were scanned on both systems with the radiation dose matched to that of the clinical examinations. Images were reconstructed using a sharp kernel, 0.6-mm (minimum) thickness for energy-integrating-detector CT, and 0.6- and 0.25-mm (minimum) thicknesses for photon-counting-detector CT. Image noise was measured and compared using adjusted 1-way ANOVA. Images were reviewed blindly by 3 neuroradiologists to assess the incudomalleal joint, stapes footplate, modiolus, and overall image quality. The ranking results for each specimen and protocol were compared using the Friedman test. The Krippendorff α was used for interreader agreement.

RESULTS: Photon-counting-detector CT showed an increase of in-plane resolution compared with energy-integrating-detector CT. At the same thickness (0.6 mm), images from photon-counting-detector CT had significantly lower (P < .001) image noise compared with energy-integrating-detector CT. Readers preferred the photon-counting-detector CT images to the energy-integrating-detector images for all 3 temporal bone structures. A moderate interreader agreement was observed with the Krippendorff α = 0.50. For overall image quality, photon-counting-detector CT image sets were ranked significantly higher than images from energy-integrating-detector CT (P < .001).

CONCLUSIONS: This study demonstrated substantially better delineation of fine anatomy for the temporal bones scanned with the ultra-high-resolution mode of photon-counting-detector CT compared with the ultra-high-resolution mode of a commercial energy-integrating-detector CT scanner.

ABBREVIATIONS: EID = energy-integrating detector; K-α = Krippendorff α; MTF = modulation transfer function; PCD = photon-counting detector; UHR = ultra-high-resolution

Multidetector CT is an essential clinical diagnostic tool for evaluating abnormalities of the temporal bone and lateral skull base.1–4 Temporal bone structures of clinical interest, such as the ossicles, facial nerve, and labyrinth, are submillimeter and require high-spatial-resolution imaging.2,5 The detector size of a CT system is one of the major factors limiting the spatial resolution needed to resolve these fine structures. Commercially available multidetector CT scanners are built using energy-integrating detectors (EIDs), in which the detected signal is proportional to the total energy deposited by all photons without specific information about an individual photon or its energy. The effective detector pixel sizes range from 0.5 to 0.625 mm at the isocenter for the commercial EIDs. Several approaches have been investigated to further improve the spatial resolution of an EID system for temporal bone imaging. One approach is to place an attenuating comb (grid) filter on top of the detector to reduce the detector aperture size.6–8 However, the attenuation of the filter inevitably reduces geometric dose efficiency because the filter blocks the
EID-CT scans were obtained with the 3 image sets (PCD-0.6, PCD-0.25, and EID-0.6) for each temporal bone specimen. The mean and SD of image noise for each ROI were matched among the 3 image sets (PCD-0.6, PCD-0.25, and EID-0.6). Noise Measurements

Image noise was measured in the cadaveric images as the standard deviation (SD) of CT numbers in a circular ROI drawn in a uniform soft-tissue area for each dataset. The size and the location of the ROIs were matched among the 3 image sets (PCD-0.6, PCD-0.25, and EID-0.6). The mean and SD of image noise for each image set were calculated.

Reader Assessment of Image Quality

The reading protocol was established on a clinical viewing station that was appropriately calibrated for routine diagnosis following the “ACR-AAPM-SIIM Technical Standard for Electronic Practice of Medical Imaging.”27 The 3 image sets (PCD-0.6, PCD-0.25, and EID-0.6) for each temporal bone specimen were displayed side by side in a random order with scanning and reconstruction information blinded to the readers. Three fellowship-trained neuroradiologists (R.J.W., K.K.K., L.J.E.), each with >10 years of experience, independently assessed the overall image quality and the delineation of 3 anatomic structures (modiolus, stapes footplate, incudomallear joint). For each specimen, images from 3 protocols were ranked from 1 to 3, with 1 being the most preferred and 3 being the least preferred. Equal rank was allowed. Thirty sets of images (10 specimens × 3 image sets/specimen) were reviewed by each of the 3 readers.

Statistical Analysis

All statistical analyses were performed using free statistical software (R Project, Version 3.4.0; http://www.r-project.org/). The differences of image noise among the 3 protocols were evaluated.
using 1-way ANOVA with subsequent Tukey honest significant difference analysis. The average ranking from the 3 readers for each specimen and protocol was compared using the Friedman test to evaluate the differences in overall image quality and diagnostic confidence for the 3 structures. Pair-wise comparisons were performed with Conover post hoc testing with a Bonferroni correction. $P < .05$ was considered statistically significant. The Krippendorff $\alpha$ ($\kappa$-$\alpha$) was used to test the interreader agreement with the following scales: 0–.20 = poor agreement, 0.21–0.40 = fair agreement, 0.41–0.60 = moderate agreement, 0.61–0.80 = substantial agreement, and 0.81–1.00 = almost perfect agreement. $^{28}$

**RESULTS**

PCD-CT showed a slightly better MTF performance than EID-CT (Fig 1). The spatial frequencies at 50%, 10%, and 2% MTF (Table 1) were 11.2, 18.4, and 21.1/cm for the PCD-CT and 10.6, 17.5, and 20.1/cm for EID-CT.

Representative images of the modiolus (Fig 2), stapes footplate (Fig 3), and incudomallear joint (Fig 4), shown side-by-side for the 3 datasets (PCD-0.6, PCD-0.25, and EID-0.6), demonstrated the improved ability to resolve each of the evaluated structures. Decreaseed image thickness resulted in enhanced visualization of the 3 submillimeter structures evaluated.

Measurements for the same image thickness (0.6 mm, Fig 5) showed that images from the PCD scanner had significantly lower ($P < .001$) image noise (mean, 55.9 ± 5.2 HU) compared with images from the EID scanner (mean, 91.8 ± 6.5 HU). The thinner 0.25-mm PCD images (mean, 89.8 ± 8.3 HU) yielded noise like that of the 0.6-mm EID images ($P = .80$).

The rank distributions from all 3 readers demonstrated that PCD-0.25 images were the most preferred, followed by the PCD-0.6 images; the EID-0.6 images were the least preferred (Fig 6). The Friedman test showed statistically significant differences in rankings for the 3 protocols ($P = .02$). Pair-wise comparison demonstrated that the readers preferred the PCD-CT images to the EID images for all 3 temporal bone structures (Table 2). Among the 3 sets of PCD images, readers preferred the PCD-0.25 images over the PCD-0.6 images for visualizing the modiolus ($P = .002$) and the incudomallear joint ($P < .001$), but no significant preference was found when assessing the stapes footplates ($P = .12$). For overall image quality, both PCD-CT image sets were ranked significantly higher than the EID images ($P < .001$), and readers preferred thinner images (0.25 mm) over thicker images (0.6 mm) from PCD-CT ($P < .001$).

Fair-to-moderate interobserver agreement was observed among the 3 readers for ranking image quality (Table 3). Readers reached moderate agreement for the modiolus ($\kappa$-$\alpha$ = 0.54) and stapes footplate ($\kappa$-$\alpha$ = 0.44) and fair agreement for the incudomallear joint ($\kappa$-$\alpha$ = 0.36). For overall image quality, moderate agreement was observed with $\kappa$-$\alpha$ = 0.50.

**DISCUSSION**

In this in vitro study, we investigated temporal bone imaging using a new PCD-CT system with a 0.25 × 0.25 mm detector size at its isocenter. Quantitative and qualitative image quality analyses
showed superior image quality and better delineation of anatomic microstructures compared with the EID-CT system on which the PCD-CT was built. Leng et al. reported the preliminary results of PCD-CT UHR imaging using various phantom and cadaveric test objects. Among these studies, 1 cadaveric temporal bone was scanned, and it was found that the PCD-CT UHR acquisition with a service-mode sharp kernel (S80) achieved 29% noise reduction compared with the EID-CT system. In this present work, with results from multiple cadaveric temporal bone specimens, we have demonstrated that with a clinical temporal bone reconstruction kernel (U70), the PCD-CT UHR mode could achieve ~40% noise reduction compared with an EID-CT system when scanning at the same dose level and reconstructing at the same image thickness (0.6 mm). The more aggressive noise reduction with PCD in this study compared with the previous report is mainly due to the kernel difference (U70 is sharper than S80). Our results indicate the potential of a 64% reduction in dose using PCD-CT for clinical temporal bone imaging to achieve the same image noise as in EID-CT. This finding confirmed the previous conclusion that PCD-CT with its direct energy conversion could substantially increase the dose efficiency of UHR acquisitions compared with the EID-CT technique using a comb filter.

Both PCD image sets (PCD-0.6 and PCD-0.25) were preferred compared with EID acquisitions because submillimeter structures were more evident on PCD images. One contribution was from the slightly improved in-plane resolution on the PCD-CT. At matched image thicknesses (0.6 mm), PCD-0.6 images had the additional benefit of significantly lower image noise than the EID-0.6 images. On the other hand, PCD-0.25 images had the benefit of improved image quality.
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PCD-CT system demonstrated better delineation of anatomic microstructures of the temporal bones compared with UHR acquisitions performed on a commercial EID-CT system.

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