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Effective Visualization of the Intracranially Implanted Neurosurgical Devices with Photon-counting Detector Computed Tomography : A Technical Note

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Abstract : Photon-counting detector computed tomography (PCD-CT) allows for attainment of images with excellent spatial resolution at reduced radiation doses. However, practical utility of this diagnostic modality in neurosurgery is still not defined well. Herein, the authors report their initial experience with the use of postoperative PCD-CT (helical pitch, 0.85 ; gantry rotation time, 0.5 s ; tube voltage, 120 kV) in a single-acquisition high-resolution mode with the iterative metal artifact reduction and attainment of the reconstructed images with slice thickness of 0.2 mm for assessment of the shunt valve pressure adjustment system and endovascular flow-diverting stent. In both cases, intracranially implanted neurosurgical devices were effectively visualized. J. Med. Invest. 72 : 463-466, August, 2025

Keywords **:** *Photon-counting detector computed tomography, Neurosurgical device visualization, Image resolution, Image quality, Radiation exposure*

INTRODUCTION

Cadmium telluride-based photon-counting detector computed tomography (PCD-CT) is often considered as disruptive technological innovation, since it accounts for energy of all individual X-ray photons (including those of low energy) converting it directly into electric signals, which amplitude is proportional to the energy of a photon. It allows for attainment of images with excellent spatial resolution at reduced radiation doses, particularly due to high signal-to-noise ratio (SNR) and significantly decreased pixel size (1-4). Indeed, in comparison with conventional CT based on energy-integrating detectors (EID), PCD-CT in high- or ultrahigh-resolution mode enables for the decrease of radiation dose by 12–30% (and even by 85% under the specific conditions) without negative impact on the image quality, increases SNR by 11–38%, and reduces requirements for the contrast agents' exposure (1-6). Moreover, PCD-CT permits reconstruction of images with the slice thickness of 0.2 mm, whereas with both conventional and dual-energy latest generation EID-based CT it is usually limited to 0.25 mm at the most (3, 7). Such advantages ultimately result in enhanced tissue characterization and prominent increase of diagnostic capabilities (2-4, 6). Other valuable benefits of PCD-CT include improvement of the contrast-to-noise ratio, reduction of electronic noise, metal, beam-hardening, and blooming artifacts, various options for spectral-based reconstructions and material decomposition based on a single acquisition, and at least theoretical possibilities for multicontrast imaging and molecular imaging with targeted nanoparticles (2-4, 6).

Usefulness of PCD-CT for breast, chest, cardiovascular, and temporal bone imaging has been highlighted previously (2, 3, 8). However, practical utility of this modality in neurosurgery is still not defined well. To assess such a diagnostic option, we performed postoperative PCD-CT by means of NAEOTOM Alpha scanner with software version syngo CT VA50 (Siemens Healthineers, Erlangen, Germany) in 2 patients with intracranially implanted neurosurgical devices, both of whom provided written informed consent before examination. This study was approved by the Clinical Research Ethics Committee of Itabashi Chuo Medical Center (approval number 221227F).

CASE 1 : VISUALIZATION OF THE SHUNT VALVE PRESSURE ADJUSTMENT SYSTEM

A 74-year-old woman with secondary hydrocephalus after subarachnoid hemorrhage underwent implantation of the ventriculoperitoneal shunt (VPS) with in-line valve pressure adjustment system (Codman® Hakim® Programmable Valve System ; Integra LifeSciences, Mansfield, MA, USA ; Fig. 1A). Initially set valve opening pressure (120 mm H_2O) was checked on the first postoperative day by means of X-ray examination. At the same time, PCD-CT (helical pitch, 0.85 ; gantry rotation time, 0.5 s) in a single-acquisition high-resolution mode with the iterative metal artifact reduction (iMAR) and utilization of the convolution kernel Hr 56 for attainment of reconstructed images with the slice thickness of either 0.4 mm or 0.2 mm was performed (Fig. 1B and C). Tube voltage and current were 120 kV and 249 mA, respectively. The radiation dose according to the volume computed tomography dose index ($CTDI_{vol}$) and the dose length product (DLP) constituted 42.7 mGy and 812 mGy * cm, respectively. Reconstructed PCD-CT images with 0.2 mm thickness provided excellent visualization of the cam position indicator.

CASE 2 : VISUALIZATION OF THE ENDOVASCULAR FLOW-DIVERTING STENT

A 50-year-old woman was diagnosed with unruptured aneurysm (size, 5 mm) of the right internal carotid artery - superior hypophyseal artery (Fig. 2A). Treatment was attained with the

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endovascular placement of flow-diverting stent (Pipeline™ Flex with Shield Technology, size, 3.75 × 16 mm ; Medtronic Neurovascular, Minneapolis, MN, USA ; Fig. 2B). During subsequent follow-up, PCD-CT (helical pitch, 0.85 ; gantry rotation time, 0.5 s) in a single-acquisition high-resolution mode with iMAR and utilization of the convolution kernel Hr 56 for attainment of reconstructed images with the slice thickness of 0.2 mm was performed on an outpatient basis. Tube voltage and current were 120 kV and 51 mA, respectively. The radiation dose according to $CTDI_{vol}$ and DLP constituted 8.67 mGy and 168 mGy ∗ cm, respectively. It allowed for excellent visualization of the stent within the lumen of the artery (Fig. 2C and D). Conventional CT was not attained in this case, since its efficacy was seemed doubtful considering high possibility of image artifacts due to radiation scattering in presence of metal stent and vicinity of the skull base bone structures (2).

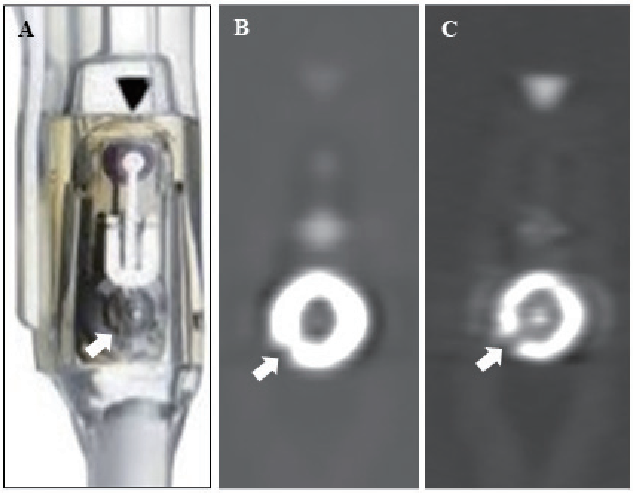

Figure 1. Visualization of the ventriculoperitoneal shunt valve pressure adjustment system (A) by means of the photon-counting detector computed tomography in a single-acquisition high-resolution mode with the iterative metal artifact reduction and utilization of the convolution kernel Hr 56 for attainment of reconstructed images with the slice thickness of 0.4 mm (B) and 0.2 mm (C). The latter provided excellent visualization of the cam position indicator (*arrow*).

DISCUSSION

Due to attainment of images with excellent spatial resolution and high SNR, PCD-CT has a great potential for use in clinical practice. In addition, possibility to reduce radiation dose and requirements for the contrast agents' exposure makes this technique attractive for cases requiring serial CT examinations, especially in pediatric patients (1-6). Particularly, NAEOTOM Alpha scanner with software version syngo CT VA50 allows for routine acquisition of reconstructed images with a slice thickness of 0.2 mm using tube voltage of 120 kV. Although occasional appearance of the ring artifact in the center of PCD-CT images (9) may potentially complicate their interpretation, we have not encountered such a problem in our initial experience with this technique. Previous studies indicated that in comparison with conventional EID-based CT, PCD-CT provides better soft tissue contrast and delineation of the complex bone structures, such as lamina cribrosa and petrous bone (2, 3, 10, 11), while other advantages of this novel imaging modality may be related to effective visualization of the implanted medical devices, particularly in neurosurgical patients as demonstrated herein.

VPS with valve pressure adjustment system are used routinely for management of hydrocephalus in both adult and pediatric patients. Eighteen different settings on the cam of the Codman® Hakim® Programmable Valve System used in our Case 1 allows to optimize precisely the valve opening pressure, which is adjusted transcutaneous by externally applied magnetic field generated by the dedicated programmer (12). Usually, the size of the cerebral ventricles during postoperative follow-up is evaluated by MRI or conventional CT with subsequent assessment of the cam position indicator during separate X-ray examination, which is specifically required after each change of the valve opening pressure. Clear detection of the cam position indicator necessitates proper positioning of the radiographic film and direction of the X-ray shot perpendicular to the plane of the valve, whereas inappropriate settings may require repeat examination(s). It may result in excessive radiation exposure, especially if serial assessments are necessary. As demonstrated herein, PCD-CT in a single-acquisition high-resolution mode with iMAR allows for attainment of reconstructed images with the slice thickness of 0.2 mm, which may be effectively used for assessment of the cerebral ventricles and visualization of the cam position indicator within the same setting without any specific requirements to the head positioning. It not only eliminates the need for separate X-ray examinations and decreases radiation exposure, but also exclude the necessity of additional patient's transfers to or within the radiology unit.

Endovascular placement of flow diverters necessitates

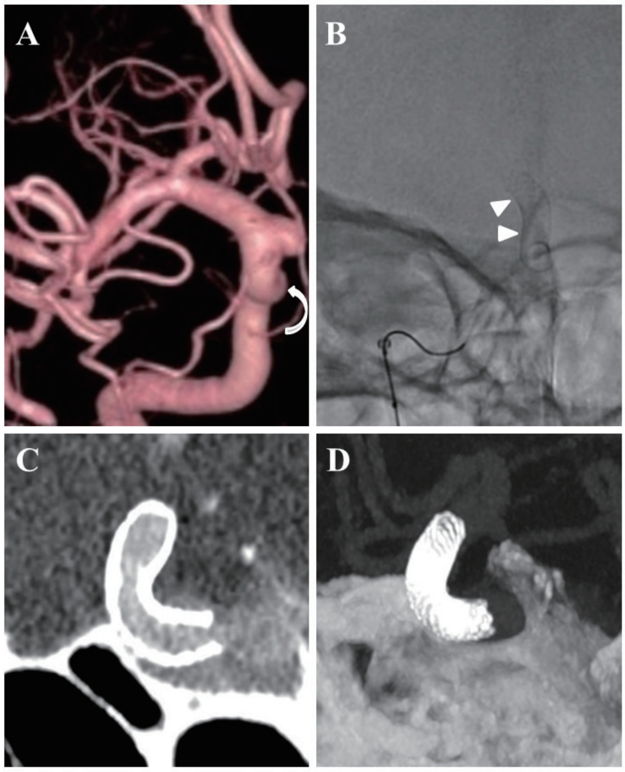

Figure 2. Imaging findings in a 50-year-old woman. Pretreatment three-dimensional (3D) computed tomography angiography (A) reveals aneurysm of the right internal carotid artery - superior hypophyseal artery (*curved arrow*). Digital subtraction angiography at anterior-posterior view (B) demonstrates position of the implanted flow-diverting stent (*arrowheads*). Sagittal (C) and 3D maximum intensity projection (D) images of the follow-up photon-counting detector CT in a single-acquisition high-resolution mode with the iterative metal artifact reduction and utilization of the convolution kernel Hr 56 for attainment of reconstructed images with the slice thickness of 0.2 mm clearly demonstrate positioning and structure of the stent within the lumen of the artery.

perioperative administration of the antiplatelet agents to prevent stent thrombosis, at least until confirmation of its patency, which is usually attained at 6-month follow-up with cerebral angiography, an invasive procedure requiring short hospital stay. Conventional CT or CT angiography (CTA) is of limited help for stent visualization in such cases owed to low SNR in presence of image artifacts caused by metal and adjacent bone structures, which may even cause an effect of artificial lumen narrowing (2, 13). Subtraction CTA may be somewhat more helpful (14), but current clinical experience with this modality in neurovascular diseases is still rather limited. Meanwhile, as was demonstrated in our Case 2, PCD-CT in a single-acquisition high-resolution mode with iMAR may allow for effective non-invasive visualization of the stent within the lumen of the artery on an outpatient basis. Of note, the radiation dose according to $CTDI_{vol}$ and DLP in this patient was prominently reduced in comparison with Case 1 reported herein, most probably due to much lower tube current (51 mA vs. 249 mA, respectively). Certainly, based on a single case it is impossible to suggest that PCD-CT may substitute standard control functional examination with cerebral angiography and that it may be more advantageous with regard to radiation dose. Recently, De Beukelaer *et al*. (13) reported results of their retrospective study on assessment of 6 endovascular stents and 9 flow diverters in 12 patients with intracranial atherosclerotic disease or wide neck aneurysms, and concluded that PCD-CTA in ultrahigh-resolution mode has a potential to reduce the need for invasive angiography for postinterventional control or during follow-up after implantation of these devices. Thus, it seems reasonable, if such a possibility would be tested further in longitudinal comparative studies, which may also consider potential effectiveness of PCD-CT and -CTA in characterization of atherosclerotic plaques and dynamics of their progression (2, 3).

Obviously, the high cost of dedicated PCD-CT scanners limits their current availability, but such a problem is typical for any newly introduced advanced medical device and hopefully will be somehow resolved in the future (4). On the other hand, the cost-benefit analysis of this innovative technology and real impacts of its advantages on treatment strategies and patients' outcomes will require separate evaluations.

CONCLUSION

Our initial experience has demonstrated that PCD-CT in a single-acquisition high-resolution mode with iMAR allows for effective visualization of the intracranially implanted neurosurgical devices, such as shunt valve pressure adjustment system and endovascular flow-diverting stent. It can be done along with assessment of the underlying brain or vascular pathology, and may eliminate the need for multiple simultaneous X-ray examinations. Notably, PCD-CT can be attained with reduced radiation exposure, which may be important if serial follow-up CT evaluations are required, especially in pediatric patients.

CONFLICT OF INTEREST DISCLOSURE

Neither author has any actual or potential conflicts of interest related to this technical note.

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