

High resolution photon counting CT permits direct visualisation of directional deep brain stimulation lead segments and markers

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Directional deep brain stimulation (DBS) leads are a recent addition to the options available for DBS. They are intended to enable current steering towards the intended therapeutic target and away from neighbouring structures, in order to increase stimulation therapeutic window (TW), i.e. the range of amplitudes achieving symptomatic relief without side effects. Some data also suggest lower energy consumption with potential IPG longevity prolongation [1].

These advantages are offset by increased programming complexity. Whereas non-directional leads typically have four contacts, directional leads from all manufacturers have eight contacts, and monopolar reviews take far longer. Newer electrodes coming to market with more than eight contacts will likely increase this problem. Anatomically guided imaging-based approaches have shown dramatic reductions in programming time [2], but require accurate determination of electrode orientation, which has proved challenging. Directional electrodes contain an orientation marker, and are typically implanted facing in a consistent direction, but orientation often shifts in the immediate period following insertion, and post-operative orientation confirmation is required. Electrode position remains stable thereafter [3].

MRI and CT imaging are unable to clearly visualise the directional contacts in vivo. Several techniques for ascertaining directional lead orientation have accordingly been described but none are without limitations.

Antero-posterior and lateral skull radiographs show the directional marker and approximate lead orientation, but accuracy is limited to around 9.5° [4]. Overlap of the left and right leads on the lateral view may make interpretation difficult, and a small amount of obliquity may be needed to separate the images of the lead tips, which is unhelpful when assessing orientation. Studies have also shown small yet significant differences between the orientation angles of the direction marker and the segmented electrodes – attributed to deviations in the tolerances in the handmade lead assembly process [5,6]. 3D fluoroscopic methods such as the ‘iron sights’ technique [4,5] improve accuracy by using both the segmented electrode contact signal and directional marker to assess orientation angle. However, to define fully the position of a directional electrode requires six values; i.e. X, Y and Z co-ordinates and three angles of electrode orientation (lead axis rotation and two tilt angles) [7].

Algorithms have been described which reconstruct electrodes based

on streak artifact. These require an angle between the lead and scanner axis of under 40–55° to ensure sufficient artifact for analysis, and they have been reported to err by 180° due to artifact symmetry – requiring additional radiographs for confirmation. Although efforts are being made to address these drawbacks and improve software automation, validation is limited to proprietary electrode brands on specific CT scanners. The methods are therefore not universally applicable [6,8].

Conventional CT scanner detectors measure X-rays by first converting them into lower energy visible photons in a scintillator layer. The photons generated are then absorbed by an underlying photodiode array, each pixel of which measures the amount of incident light and generates an electrical signal proportional to the total energy deposited during a measured interval. In contrast, recently developed photon-counting detectors (PCDs) do not require a separate scintillator but rather convert x-ray photons directly into an electrical signal within a single thick semiconductor layer. Unlike the aggregate signal measured with a conventional detector, the signal generated by each X-ray photon can be picked up individually, and the size of the signal gives a measure of the energy of that photon [9]. A threshold can be imposed such that signals below a certain energy are ignored, greatly reducing noise.

PCDs also allow improved resolution, by eliminating both the problem of X-ray scatter within scintillator layers, and the collimator grid that is used to control the scatter. Overall, PCDs permit sharper images with improved contrast-to-noise ratio, spatial resolution and artifact reduction – all without the requirement of increased radiation dose needed to offset noise in conventional imaging [9].

We illustrate here how high-resolution photon counting CT can directly visualise directional lead contacts and orientation markers in vivo, both on CT and when fused to MRI, obviating the need for additional examinations and analyses.

We employ a standard CT brain protocol (Scan Mode: Routine Spiral Adult Head Quantum Plus Xcare; Tube Voltage: 120 kV; Detector collimation: 144 × 0.4 mm; Image Quality Level: 110; Volume CT dose index (CTDIvol): 52.6; Pitch: 0.55; Rotation Time(secs) 0.5; Slice Thickness: 0.6 mm; Slice Increment: 0.6mm; Reconstruction Kernel: HR40; Quantum Iterative Reconstruction (QIR) strength: 2; Matrix size: 512 x 512), with high resolution imaging covering the region from the tip of the lead to just above the orientation marker (Scan Mode: Routine

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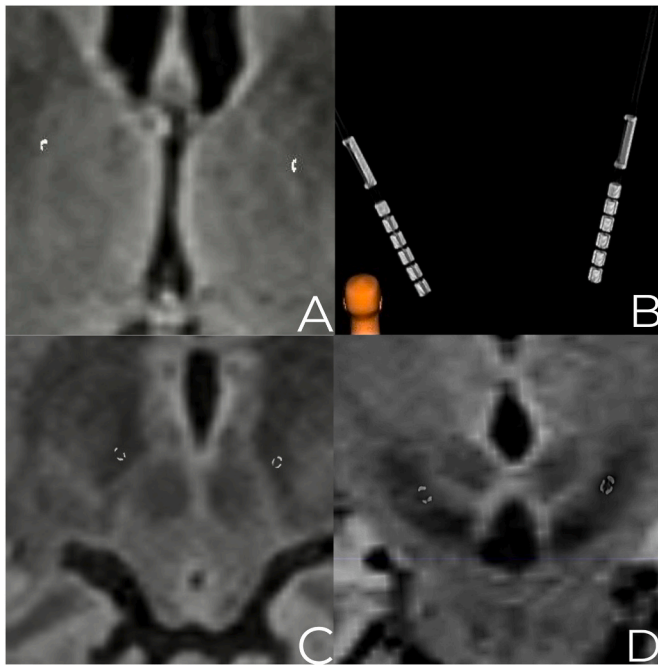


Fig. 1. A Pre-operative axial FLAIR MRI fused with post-op PCD-CT to illustrate directional orientation markers. B Photon-counting (PCD) CT 3D rendering of DBS electrodes illustrating both directional markers and segmented contacts. C and D Post-operative PCD CT electrode imaging fused to pre-operative 3T MRI FLAIR sequences on planning software displaying directional segmented contacts in axial (C) and coronal (D) planes within the STN.

Spiral Adult Head High Resolution Ultra Quantum Plus; Tube Voltage: 120 kV; Detector collimation: 120×0.2 mm; Image Quality Level: 110; Volume CT dose index (CTDIvol): 18.69; Pitch: 1 (adapted); Rotation Time(secs) 1; Slice Thickness: 0.2mm; Slice Increment: 0.2mm; Reconstruction Kernel: HR98 (adapted for wire tip visualisation); Quantum Iterative Reconstruction (QIR) strength: 3; Matrix size: 1024×1024 .

In this example case, directional DBS leads were inserted to bilateral subthalamic nuclei targets (Boston Vercise Cartesia X; Boston Scientific, Marlborough, USA). A post-operative PCD CT was obtained (Siemens Naeotom Alpha Version VA50; Siemens Healthineers, Forchheim, Germany). The images were then co-registered with the 3T pre-operative MRI scan on a DBS planning workstation (Renishaw Neuroinspire, Renishaw, Gloucester, UK). (Fig. 1).

Ionisation radiation doses of dose length product (DLP; mGy*cm) for the CT brain and high-resolution electrode imaging were 909 and 87.5 respectively. This approximates to effective doses of 1.8 mSv (CT brain) and 0.175 mSv (electrode imaging) [10]. Despite providing greater imaging detail, the combined dose of both sequences is comparable to or lower than conventional CT brain alone – typically around 2.1–2.3 mSv. If employed, 3D rotational fluoroscopy would have added a further c. 0.2 mSv to conventional imaging [4].

Currently the main drawback to PCD imaging is limited availability. However, the benefits of photon counting CT have now been shown in multiple areas [9], resulting in FDA clearance for clinical use in September 2021, and we hope that the potential benefits of this

technology for DBS patients will quickly become more accessible.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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