2026 JULY 19–22 VANCOUVER, BC
JOINT AAPM | COMP MEETING

# Independent Verification Framework for DirectSPR Commissioning In DECT-Based Proton Therapy Planning

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## ABSTRACT

**Purpose:**
Stopping power ratio (SPR) estimation from dual-energy CT (DECT) may improve proton range accuracy by eliminating conventional HU calibration uncertainties. Commercial proprietary algorithms, such as DirectSPR, necessitate independent verification methods during commissioning. We developed a commissioning framework using DEEDZ-SPR as an independent verification tool to validate DirectSPR implementation against our clinical single-energy CT (SECT) workflow.

**Methods:**
A head-and-neck patient underwent DECT (100kVp/Sn150kVp) scanning and treatment using 100 kVp images. The clinical plan was recalculated on DirectSPR (Siemens Syngo.via) and DEEDZ-SPR images. SPR distributions within the 10% dose region were compared using the Kolmogorov-Smirnov (KS) test. Dosimetric evaluation compared D95%, V95%, conformity index (CI), and homogeneity index (HI). Gamma analysis (3%/3mm, 10% threshold), robustness evaluation (±3mm/±3.5%), and range difference (R90) along a beam traversing heterogeneous anatomy were assessed.

**Results:**
SPR distributions differed significantly ($p<0.05$) between DirectSPR and DEEDZ-SPR, yet dosimetric equivalence held: CTV70 D95% ranged 70.37–70.48 Gy (≥66.5 Gy criterion), V95%>99.97%, with negligible CI/HI differences. Gamma passing rates were 99.26% (DirectSPR) and 98.14% (DEEDZ-SPR); robustness held across all 28 scenarios. LET and R90 also differed between methods.

**Conclusion:**
This framework validates DEEDZ-SPR as an independent verification tool for DirectSPR, confirming dosimetric equivalence to clinical SECT planning and validating current range margins for SPR uncertainties.

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## INTRODUCTION

Range prediction relies on the stopping power ratio (SPR), which governs how far a proton travels through tissue relative to water. Conventionally, SPR is derived from single-energy CT (SECT) using a Hounsfield Unit look-up table (HLUT), where measured CT numbers are mapped to SPR via a piecewise linear calibration curve. While well-established, this approach is fundamentally limited by the degeneracy of the Hounsfield unit: tissues with identical CT numbers can have different SPRs depending on their elemental composition, contributing the dominant term to the clinical range uncertainty budget of 3.5%.

Dual-energy CT (DECT) addresses this limitation by reducing reliance on empirical calibration and eliminating much of the composition-dependent ambiguity. There are two distinct DECT-based approaches (1) DirectSPR (Siemens Healthineers) is a commercially implemented algorithm and (2) DEEDZ-SPR, developed by Saito and colleagues, takes a complementary approach where SPR is estimated from a weighted linear combination of two CT acquisitions at different tube voltages. Both methods bypass the conventional HLUT, but differ in their mathematical formulation, calibration requirements, and vendor implementation — making them suitable as independent cross-checks of one another. This study aims to establish a commissioning framework to validate DirectSPR implementation for clinical use. Agreement between DirectSPR and DEEDZ-SPR provides a cross-validation that strengthens the confidence in the DECT-derived SPR maps prior to clinical deployment.

## METHODS AND MATERIALS

Five patients with head and neck malignancies undergoing proton therapy were prospectively recruited. All patients provided informed consent. All patients were scanned on a Siemens Somatom X.Cite CT scanner. DECT acquisition was performed using a Twin Sprial protocol at 100 kVp and tin-filtered 150 kVp (Sn150 kVp), with the institutional clinical standard scan parameters. The 100 kVp images served as the primary clinical dataset throughout: radiation oncologists performed target volume and OAR delineation exclusively on the 100 kVp images, and subsequently treatment planning was performed and approved on the dataset using the SECT HLUT. All patients were treated according to this standard clinical plan. The DECT acquisition therefore introduced no modification to the clinical workflow; the Sn150 kVp acquisition was obtained as an adjunct dataset for generating SPR images.

SPR images were generated using DirectSPR methods and DEEDZ-SPR methods. The approved clinical treatment plan for each patient was recalculated using RayStation. Voxel-wise SPR distributions were extracted within the 10% isodose region of the clinical plan for each SPR method. Pairwise comparisons between DirectSPR, DEEDZ, and HLUT were performed using the two-sample Kolmogorov-Smirnov (KS) test, which assesses whether two distributions are identical. Dosimetric agreement between plans calculated on each SPR dataset was assessed using the following metrics, evaluated on the clinical target volume (CTV) and all contoured organs at risk: D95%, V95%, conformity index (CI), and homogeneity index (HI). Gamma analysis (3%/3mm, 10% threshold), robustness evaluation (±3mm/±3.5%), and range difference (R90) along a beam traversing heterogeneous anatomy.

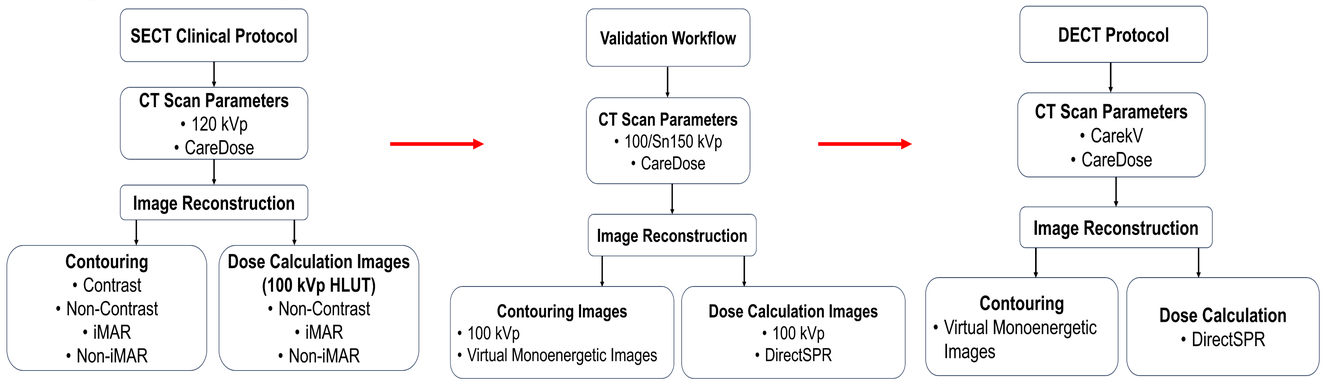


**Figure 1.** Possible transition from current clinical SECT workflow to validation of DirectSPR workflow to DirectSPR clinically ready workflow.

## RESULTS

Based on the KS statistic, SPR distributions differed significantly between DirectSPR and DEEDZ-SPR from SECT images across the whole image volume (DirectSPR D=0.124, DEEDZ-SPR D=0.254; both $p<0.001$) and within 10% isodose region (**Fig. 2**) (D=0.131 DirectSPR, D=0.268 DEEDZ-SPR), indicating the difference is intrinsic to the algorithms rather than background voxels.

- **Dosimetric Evaluation:** Despite these differences, standard clinical endpoints remained equivalent: CTV70 D95% ranged 70.37–70.48 Gy (criterion ≥66.5 Gy), V95% exceeded 99.97%, and CI/HI differences were negligible for both methods.
- **Gamma and Robustness:** Gamma passing rates (3%/3mm, 10% threshold) were 99.26% (DirectSPR) and 98.14% (DEEDZ-SPR); robustness was confirmed across all 28 uncertainty scenarios (±3 mm / ±3.5%).
- **LET and Range:** Along a beam traversing tissue, bone and air, DEEDZ-SPR produced a higher peak LETd (20.82 keV/μm) than DirectSPR (13.78) and SECT images (12.04), with larger mean LET deviation (+0.149 vs +0.071 keV/μm) (**Figs 3 and 4**). R90 shifts were larger for DEEDZ-SPR (+2.73 mm) than DirectSPR (+1.64 mm), consistent with its greater SPR divergence, though both remained within robustness margins.

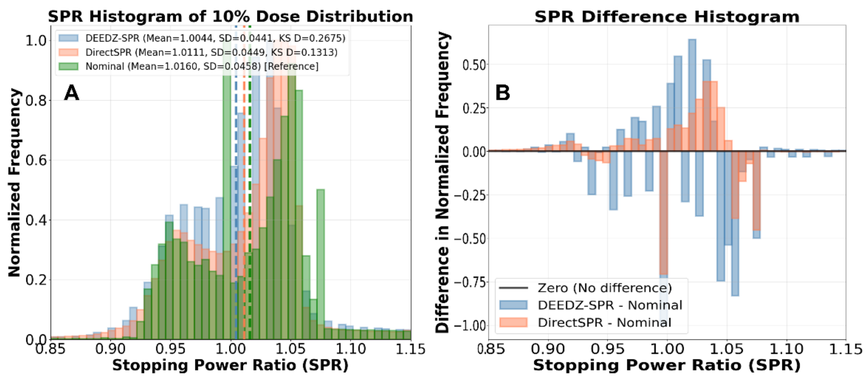


**Figure 2.** (A) shows the SPR Histogram (10% Dose Distribution) of SECT images, DirectSPR images and DEEDZ-SPR images. (B) shows the difference in the histogram between DirectSPR – SECT Images and DEEDZ-SPR – SECT Images.

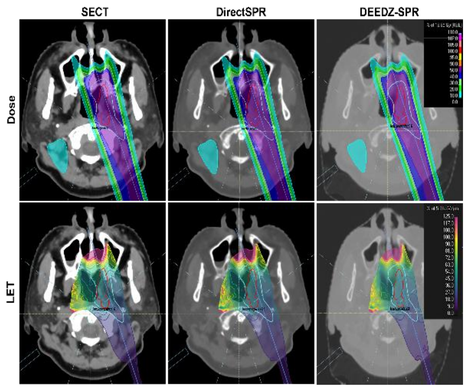


**Figure 3.** shows the dose and LET line profile of a treatment field for SECT, DirectSPR and DEEDZ-SPR image sets. The line represents the profile for comparison.

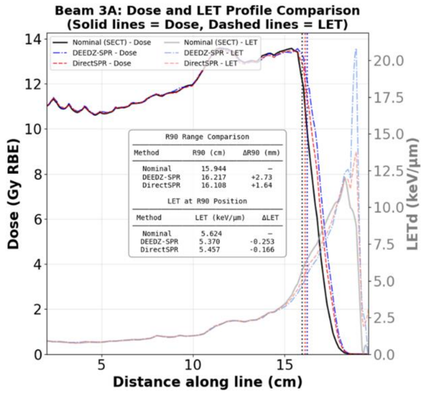


**Figure 4.** shows the R90 and LET difference of an individual treatment beam across 3 image sets.

## CONCLUSIONS

We developed and validated a commissioning framework using DEEDZ-SPR as an independent check for the proprietary DirectSPR algorithm. Although DEEDZ-SPR showed larger SPR, dose, and LET deviations, both methods remained dosimetrically equivalent to clinical SECT planning under standard endpoints and robustness margins. The higher LET hotspots seen with DEEDZ-SPR warrant caution near critical structures. As a single-patient case study, broader validation across sites and beam geometries is needed before routine clinical adoption.