

Pitfalls and Practical Protocol Optimization for Low-Pitch Spiral 4DCT Mode: Assessment of Static Image Quality in Terms of Noise, Artifacts, and Slice Sensitivity Profile

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ABSTRACT

Purpose: To assess how low-pitch spiral 4DCT affects image quality, particularly noise, artifacts, and slice sensitivity profile (SSP), to help address the limitations of this technique.

Methods: Two CT scanners, the Siemens Biograph PET/CT (S-type scanner) and the Philips Brilliance Big Bore CT (P-type scanner), were used with low-pitch spiral 4DCT protocols on phantoms of various water-equivalent diameters (WED: 27, 30, 33 cm). Noise was measured using a global noise index (GNI), and artifacts were assessed qualitatively. Z-resolution was compared across axial, spiral, and low-pitch 4DCT modes with an SSP phantom. Correlations between GNI and scan parameters were analyzed with Spearman's rank test..

Results: In the P-type scanner, GNI correlated strongly with mA (-0.836) and pitch (-0.793), moderately with WED (0.453), and weakly with CTDI_{vol} (-0.192) and gantry cycle (0.245). The GNI in the S-type scanner correlated strongly with GNI and CTDI_{vol} (-0.618), and moderately with mA (-0.536) and WED (0.442). A prominent ring artifact was consistently seen at mA < 100 for WED=33 cm in P-type, but S-type showed no artifacts under similar low mA conditions. P-type demonstrated sharper SSP in axial mode, whereas S-type better preserved SSP shape in spiral mode. For both scanners, the full width at half maximum (FWHM) of the SSP increased slightly in low-pitch 4DCT mode but stayed within 0.3 mm of the nominal slice thickness.

Conclusion: Appropriate low-pitch 4DCT protocols are essential to balance image quality and radiation dose. The effects of low mA settings should be evaluated for new scanners using this approach..

INTRODUCTION

Four-dimensional computed tomography (4DCT) is vital in radiotherapy for capturing tumor and organ motion from breathing. Multislice CT (MSCT) allows retrospective 4DCT by collecting images over several breathing cycles and sorting them by respiratory phase. MSCT scanners offer fast scanning and large imaging volumes. Both cine and low-pitch spiral modes help ensure accurate reconstruction, each meeting the data sufficient condition (DSC) during acquisition.

Research has described 4DCT motion artifacts. Yamamoto et al¹. examined artifact types and frequencies in cine mode. Dou et al². found motion errors in low-pitch protocols, while Sentker et al³. linked DSC violation artifacts to SBRT outcomes for lung and liver metastases.

Low-pitch spiral 4DCT image quality is unclear. Lower mA increases noise. Low pitch also reduces z-resolution. Current guidelines ignore how helical pitch, dose modulation, and patient attenuation interact, providing no clear thresholds for protocol reliability or artifact risk by body type. This study evaluates the quality of low-pitch 4DCT images across scanners by measuring noise, artifacts, and SSP, to help clinicians develop reliable protocols.

METHODS AND MATERIALS

A. Quantitative noise assessment and qualitative ring artifact evaluation

- CT image noise was measured using the global noise index (GNI)⁴, calculated for each slice using a sliding 10x10-pixel window. GNI represents the mode of the noise histogram for regions with a gradient magnitude below 10
- Ring artifacts were qualitatively assessed on each CT image. Assessments included WED, mA, and CTDI, with mA and CTDI values extracted from the DICOM header.
- Spearman's rank tests were used for statistical analysis to evaluate the correlation coefficient (CC) between GNI and 4DCT parameters. Correlation strength was classified as strong ([0.6, 0.8]), moderate ([0.4, 0.6]), or weak ([0.2, 0.4]).

B. Analysis of slice sensitivity profile (SSP)

- A Siemens QA phantom with a slice thickness ramp insert was used to assess pitch impact on SSP.
- SSP_{w50%} defines the slice thickness and is computed as FWHM × tan(26.634°), with 26.634° as the nominal ramp angle. SSP_{w20%} is computed as FW20M × tan(26.634°) to evaluate ramp image spread. (FW20M: Full width of 20% Maximum)
- SSP_{w50%} and SSP_{w20%} for low-pitch 4DCT were compared to axial scans. ΔSSP_{w20%/w50} = SSP_{w20%} - SSP_{w50%} quantifies the SSP tail, reflecting z-resolution for different scan modes.

RESULTS

- In the P-type scanner (no Automatic Exposure-AEC), mA is less than 100 in pitch = 0.042 with mAs ≤1200 and in pitch = 0.06 with mAs ≤800 (Figure 1), the CT images of WED = 33 cm scanned with this setup show severe ring artifacts (Figure 2).
- In the S-type scanner (with AEC), mA is below 100 mA for WED = 33 cm when QRF <70 (Figure 1). No artifact appears at any CT images scanned with low mA (Figure 2); however, GNI is greater than 20 when QRF <70 (Figure 1 & 2).
- Z-resolution decreases more in the low-pitch spiral 4DCT than in the spiral non-4DCT mode, with greater degradation observed in the P-type (1.16 mm) compared to the S-type (0.64 mm) scanner (Figure 3).

DISCUSSION

Image quality is degraded in low-pitch 4DCT mode with higher noise and artifacts compared to non-4DCT mode. To mitigate the limitation of the low-pitch 4DCT exam:

- In a P-type scanner, avoid using pitch = 0.042—especially for larger patients. At pitch = 0.06, use 800 mAs (CTDI_{vol} = 47.4 mGy) when BMI (body mass index) <28 and 1000-1200 mAs (CTDI_{vol} = 59.2-71 mGy) when Body Mass Index (BMI) ≥28.
- In the S-type scanner, use QRF ≥70 (CTDI_{vol} = 36, 56, and 76 mGy for WED of 27, 30, and 33 cm, respectively).
- Avoid the arm-down position in low-pitch 4DCT mode to prevent streak artifacts caused by incoherent offset and photon starvation of the detector response, especially in the P-type scanner.

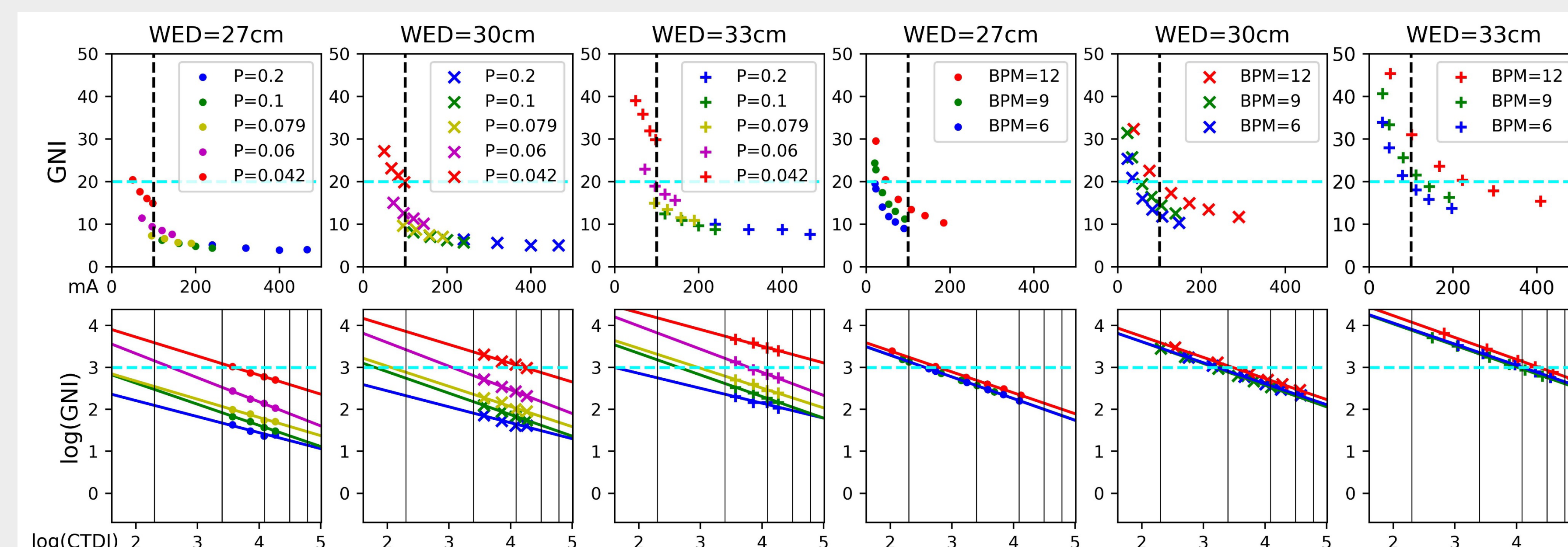


Figure 1. Scatter plots in the upper row show GNI versus tube current (mA) for the P-type scanner at different pitches (first three columns) and for the S scanner at various respiratory rates, breaths per minute (BPM) (last three columns). Each dot indicates the calculated GNI for a specific mAs (600, 800, 1000, 1200) or QRF (20, 30, 50, 70, 90, 120) for each scanner. The lower scatter plots show a linear fit of log-scaled GNI versus CTDI_{vol}. The cyan dashed line indicates the tolerable GNI level; the black dashed line shows mA = 100; and the solid black lines represent CTDI_{vol} values of 10, 30, 60, 90, and 120 mGy, respectively.

CONCLUSIONS

Customizing protocols is necessary for artifact-free scans. Low-pitch spiral 4DCT at low mA often causes artifacts, especially with arms down. For Philips Big Bore scanners, avoid pitch 0.042; use mAs ≥800 at pitch ≥0.06; and for patients with BMI ≥28, use 1000–1200 mAs at pitch 0.06. Siemens Biograph scanners perform well with QRF ≥70 and no ring artifacts. Evaluate low mA effects on image quality and SSP in new scanner setups.

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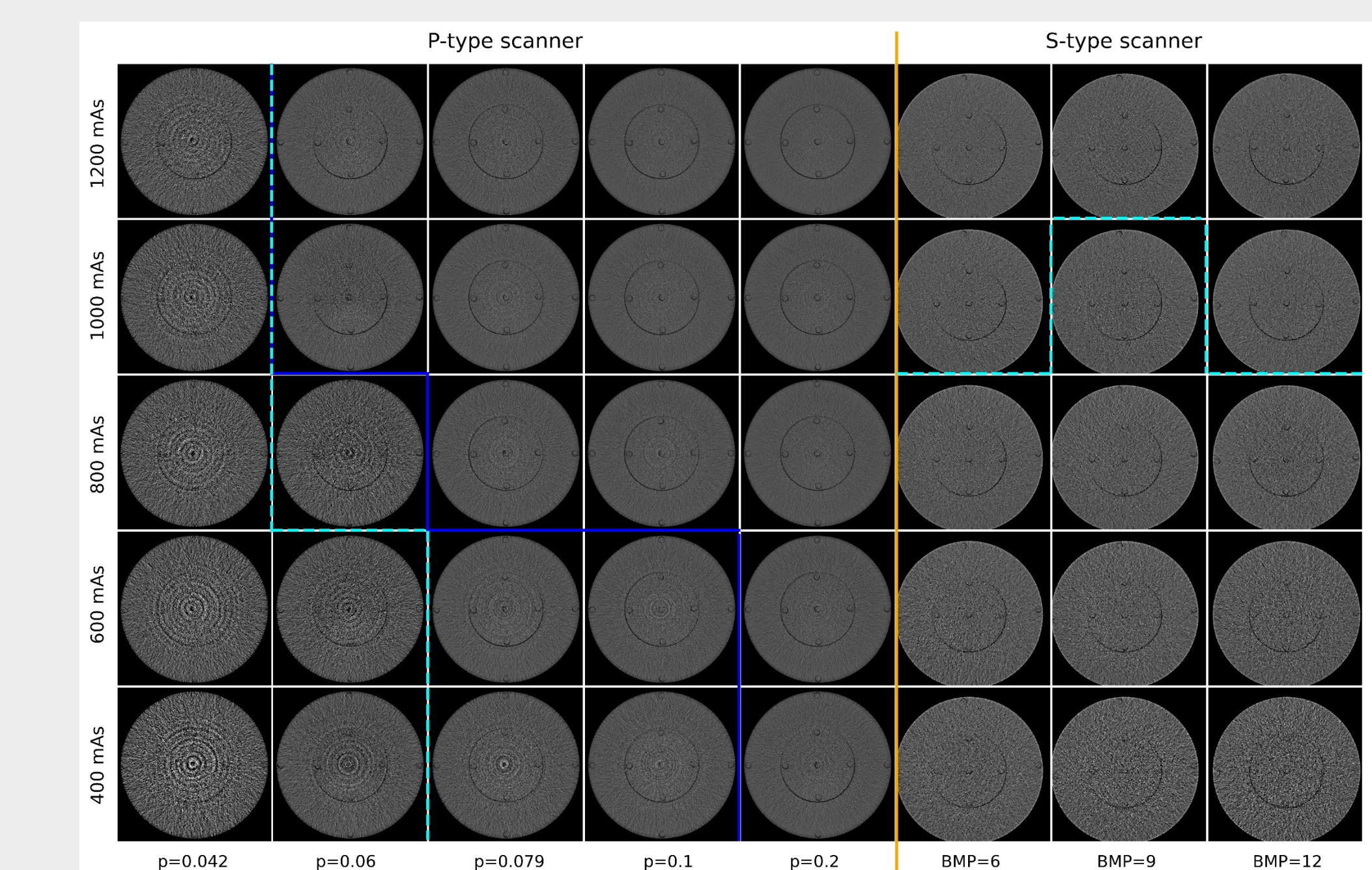


Figure 2. The diagram shows CT images of a 33 cm phantom with WED scanned using different combinations of pitch and mAs settings on the Philips Big Bore CT scanner (left of the orange line), or with different combinations of BPM and QRF settings on the Siemens Biograph PET/CT scanner (right of the orange line).

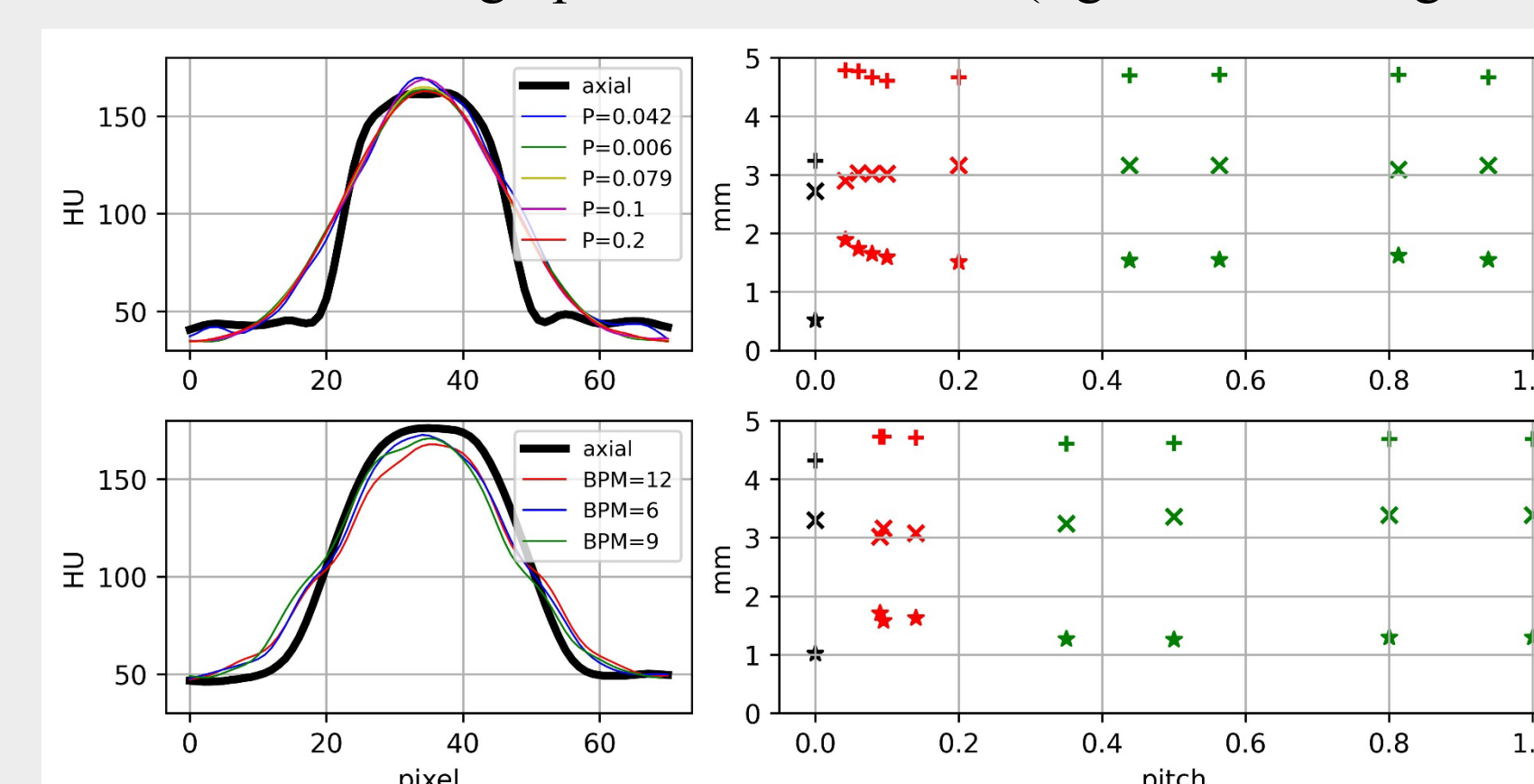


Figure 3. Left, SSP curves for different low-pitch spiral scans compared to SSP scans in axial mode; Right, scatter plots of SSP_{w20%} ('+'), SSP_{w50%} ('x'), and ΔSSP_{w20%/w50} ('*') for images scanned in axial (black), spiral non-4DCT (green), and low-pitch spiral 4DCT (red) modes. The top and bottom rows display P-type and S-type scanners, respectively.

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