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Feasibility of a Low Injection Rate Protocol for Bronchial Artery Imaging Using Spectral CT Angiography

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Abstract

Rationale and Objectives: Computed tomography (CT) angiography of the bronchial artery (BA) typically requires high-concentration iodine contrast agents and high injection rates to achieve adequate vessel enhancement, which increases the risks of contrast extravasation and renal burden. Spectral CT with monochromatic imaging can improve vascular contrast at lower energy levels (<70 keV) by enhancing the photoelectric effect of iodine. This study aimed to evaluate the feasibility of a low-injection-rate contrast protocol combined with spectral CT for BA imaging.

Materials and Methods: One hundred nine patients (72 males, 61.05±12.72 years) who underwent chest spectral CT angiography (GE Revolution 256) with a low injection rate (≤3.0 mL/s, 60–70 mL of 350 mgI/mL iohexol) were retrospectively enrolled. Monochromatic images at the optimal keV (determined by the optimal contrast-to-noise ratio [CNR] curve), 60 keV, and 70 keV were reconstructed. The signal-to-noise ratio (SNR), CNR, and subjective image quality scores (5-point scale) of the BA were compared among the three groups using non-parametric tests with Bonferroni correction.

Results: A total of 253 BAs (125 left, 128 right) were displayed. The optimal monochromatic energy for BA ranged from 40 to 50 keV (mean: 43.62±2.19 keV). Significant differences in SNR, CNR, and subjective scores were observed among the three groups (all $P < 0.05$). The optimal keV group (approximately 44 keV) yielded the highest CNR and best image quality on maximum intensity projection, volume rendering, and fused images.

Conclusion: Under a low-contrast-injection-rate protocol, spectral CT angiography at approximately 44 keV provides optimal CNR and significantly improves BA image quality, offering a reliable imaging method for BA evaluation.

Keywords: Bronchial artery; Spectral CT; Monochromatic imaging; Contrast-to-noise ratio; Low injection rate

INTRODUCTION

CT spectral imaging represents a major breakthrough in medical imaging following the advent of multi-detector row CT. Monochromatic imaging, a key technique of spectral CT, has attracted particular clinical attention. At lower energy levels (<70 keV), the photoelectric effect of iodine contrast agents is substantially enhanced, markedly improving the contrast between vessels and surrounding tissues. Consequently, diagnostic image quality can be achieved even with lower iodine concentrations (1,2).

The bronchial artery (BA) possesses unique anatomical and physiological characteristics. As a small nutrient artery of the systemic circulation, it typically originates from the thoracic aorta, has a small diameter, and frequently exhibits anatomical variations. In preoperative evaluations for conditions such as hemoptysis, CT angiography (CTA) of the BA demands high vessel visualization rates and image clarity to precisely delineate the course, origin, and branching morphology of these small vessels, thereby providing detailed anatomical information for bronchial artery embolization (BAE) (3–5).

In conventional CT angiography, achieving satisfactory vascular enhancement has clinically necessitated the use of high-concentration iodine contrast agents, large contrast volumes (80–100 mL), and relatively high injection rates (4–6 mL/s). Current scanning protocols for BA CTA predominantly remain based on conventional high injection rates. For example, multiple studies on BA CTA have employed a high-concentration contrast agent of 350 mgI/mL with injection rates reaching up to 6 mL/s. Other studies have maintained injection rates of 4.0–4.5 mL/s, with only minimal rate reduction (6,7). Although conventional protocols achieve satisfactory image quality in most cases, they carry non-negligible clinical risks: large-sample studies have demonstrated that high injection rates increase the risk of contrast extravasation, high iodine burden exacerbates renal impairment in patients with renal insufficiency, and high radiation doses pose long-term health risks (8,9).

This study aimed to apply spectral CT technology with a low-injection-rate contrast protocol for BA CTA. By comparing image quality at different monochromatic energy levels after spectral CT scanning, we systematically evaluated this protocol's performance in terms of vascular enhancement, objective image quality metrics (CT number, signal-to-noise ratio [SNR], contrast-to-noise ratio [CNR]), BA visualization rate, and subjective diagnostic confidence. The objective was to validate the feasibility of a low-injection-rate spectral CT protocol for BA imaging and to provide evidence-based support for the development of safer, individualized BA CTA protocols in clinical practice.

MATERIALS AND METHODS

Patient Selection

This retrospective study was approved by the institutional review board, and the requirement for informed consent was waived. Consecutive patients who underwent chest spectral CT

angiography (GE Revolution 256) with a low-injection-rate contrast protocol (≤3.0 mL/s, 60–70 mL of 350 mgI/mL iohexol) between March 2024 and May 2025 were retrospectively reviewed. The inclusion criteria comprised patients who underwent CTA examination due to hemoptysis, pulmonary tumors, or other conditions requiring bronchial artery evaluation. Additional inclusion criteria were: (1) age ≥ 18 years; (2) complete clinical and imaging data available for analysis; and (3) image quality sufficient for bronchial artery identification and quantitative assessment (signal-to-noise ratio and contrast-to-noise ratio measurements).Exclusion criteria were: (1) images not meeting quality requirements (respiratory motion artifacts, superior vena cava contrast hardening artifacts; n=8); (2) no BA visualization (n=8); and (3) faint BA opacification precluding CT number measurement (n=2). The final study cohort comprised 109 patients (72 men, 37 women; mean age 61.05±12.72 years; range 25–85 years).

CT Scanning Protocol

All scans were performed on a GE Revolution 256-slice CT scanner. Spectral imaging (GSI) mode was used with rapid automatic tube voltage switching between 80 kVp and 140 kVp, automatic tube current modulation, and a scan range from the thoracic inlet to the diaphragm. Section thickness and interval were 5 mm, with reconstruction thickness and interval of 0.625 mm. Contrast medium (CM) dosage was individualized following the weight-based iodine-delivery principle (standard: 450–500 mg I/kg). To evaluate the feasibility of a safer protocol, we deliberately adopted a reduced-volume regimen of 60–70 mL iohexol (350 mg I/mL), adjusted by body weight (60 mL for ≤65 kg; 70 mL for >65 kg), corresponding to a total iodine load of 21.0–24.5 g per patient. All injections were administered via an 18-gauge or 20-gauge antecubital venous cannula using a dual-syringe power injector at a low flow rate of ≤3.0 mL/s (range: 2.0–3.0 mL/s), substantially lower than conventional CTA rates (4.5–6.0 mL/s), followed by a 30-mL saline flush. A bolus-tracking technique was used for scan

triggering. The region of interest (ROI) was placed on the descending aorta at the level of the fifth thoracic vertebra (T5), and scanning was automatically initiated when the CT number within the ROI reached a threshold of 150 HU.

Image Processing and Quality Assessment

Raw data were transferred to a postprocessing workstation (AW4.7, GE Healthcare). Monochromatic images were reconstructed and analyzed using spectral analysis software. Optimal monochromatic images were obtained using the optimal CNR curve. Because 70-keV monochromatic images provide CT numbers similar to those of conventional 120-kVp imaging in muscle tissue, the SNR and CNR of 70-keV images served as reference standards (10,11). Based on previous studies , 60-keV monochromatic images were selected as another comparison group for small-artery visualization(12). SNR and CNR values were compared statistically among three groups: optimal keV, 60 keV, and 70 keV. The three sets of monochromatic data were further postprocessed using maximum intensity projection (MIP), volume rendering (VR), and three-dimensional fusion of BA and bronchial trees. All three groups were processed under identical scanning and reconstruction conditions.

Objective Evaluation

Circular ROIs (1–3 mm²) were placed on the BA, the surrounding stroma at the same level, and the subcutaneous fat of the posterior chest wall, and the CT numbers and standard deviations (SD) were measured. SNR was calculated as SNR = CT_1/SD, and CNR as CNR = (CT_1 − CT_2)/SD, where CT_1 is the CT number of the BA, CT_2 is the CT number of the peribronchial stroma in the same mediastinal plane, and SD is the standard deviation measured from subcutaneous fat (Fig.1.A). Because the location of the stromal ROI affects the optimal energy level for maximum CNR, measurements were repeated three times using magnified 0.625-mm

thin-section images at the same level to minimize partial volume effects. The mean values of the three measurements were used for analysis.

Subjective Evaluation

Two radiologists (each with >10 years of chest CT interpretation experience) independently scored the subjective image quality of the BA in the three groups (optimal keV, 60 keV, and 70 keV), and the mean scores were used. A 5-point scale was employed according to the literature (13), using BA clarity and edge sharpness as the evaluation criteria: 5 = very clear with sharp margins; 4 = clear with generally smooth margins; 3 = identifiable with discernible margins; 2 = blurred margins but still discernible; 1 = indistinct and unidentifiable.

Classification and Statistical Analysis

BA origins, branching patterns, and numbers were recorded according to actual origin sites. Branching patterns were classified using previously described methods (14–16): left and right BAs were labeled L and R, respectively, with the number of branches denoted as n, and the pattern recorded as LnRn. For common trunk arteries, the pattern was recorded after bifurcation based on actual distribution along the left and right bronchial walls. Statistical analysis was performed using SPSS version 27.0. CNR, SNR, and subjective scores among the three BA groups showed non-normal distributions; thus, the non-parametric Kruskal-Wallis test was used for intergroup comparisons, followed by pairwise comparisons with Bonferroni correction. A P value <0.05 was considered statistically significant.This retrospective study was approved by the Institutional Review Board (IRB) of the authors' institution (Approval No.2023-KL-074., dated November 1, 2023]). The requirement for informed consent was waived by the IRB because of the retrospective nature of the study and the use of anonymized clinical data.

RESULTS

A total of 253 BAs (125 left, 128 right) were visualized in the 109 spectral chest CT cases. Origins and numbers are summarized in Table 1. Ten branching patterns were observed: L1 (n=7), L2 (n=1), L1R1 (n=44), L2R1 (n=16), L3R2 (n=3); R1 (n=16), R2 (n=1), R2L1 (n=9), R2L2 (n=10), R3L1 (n=2). The L1R1 pattern was most common, accounting for 40.37% of cases (Table 2). The optimal monochromatic energy range for achieving the highest CNR of the BA was 40–50 keV (mean: 43.62±2.19 keV;Fig.1.B). Statistically significant differences in SNR, CNR, and subjective scores were observed among the 70-keV, 60-keV, and optimal CNR monochromatic groups (all $P<0.05$; Table 3). Postprocessed images (MIP, Fig.2; VR, Fig.3; BA-bronchus fusion VR, Fig.4) further demonstrated superior image quality in the optimal monochromatic group compared with the 60-keV and 70-keV groups.

DISCUSSION

This study demonstrated that, under a low contrast injection rate, virtual monochromatic images at approximately 44 keV obtained with spectral CT angiography provide optimal CNR and significantly improve BA image quality compared with conventional 60-keV and 70-keV images.

Monochromatic spectral CT angiography allows easy determination of the optimal energy level for maximizing CNR via the optimal CNR curve, thereby balancing vessel contrast and image noise (17,18). In our study, the optimal CNR range was 40–50 keV (mean: 43.62±2.19 keV). The physical basis is that energy levels close to the iodine K-edge (33.2 keV) are dominated by the photoelectric effect, substantially amplifying iodine attenuation and thus greatly enhancing vessel-to-background contrast. This technical advantage is particularly critical for small-diameter (1–2 mm), tortuous BAs with high anatomical variability. A previous spectral CT study of BAs reported an optimal CNR at approximately 63 keV (19), while optimal energy levels for other vascular beds (e.g., superior mesenteric artery (20), coronary artery (21))

ranged from 50 to 70 keV. The differences from our findings (40–50 keV) may be attributable to variations in scanner type, contrast injection protocols, and sample characteristics.

Higher contrast density (i.e., higher CT number) during the arterial phase is associated with clearer vessel visualization and greater diagnostic value (22). Multiple studies have confirmed a positive correlation between vascular CT attenuation values and CTA image quality. Pfaff et al. clearly stated that the diagnostic value of CTA depends critically on intraluminal contrast density, with higher CT numbers directly corresponding to clearer vessel depiction (23). Furthermore, Lennartz et al. provided quantitative evidence that reconstruction techniques yielding higher CT numbers—such as 40-keV virtual monochromatic images—enable vascular assessment comparable or superior to conventional acquisitions, a conclusion validated by both objective measurements and subjective visual scoring (24). Our findings corroborate these observations: the mean BA CT attenuation in the optimal energy group was 517.46±140.11 HU, and the proportion of patients with BA attenuation exceeding 400 HU (76.15%) was significantly higher than that in the 60 keV and 70 keV groups, further confirming the positive correlation between vascular CT attenuation and CTA image quality.

From a safety perspective, reducing the injection rate significantly lowers the risk of contrast extravasation, while decreasing the iodine delivery rate alleviates renal metabolic burden, making the protocol more favorable for patients at high risk of chronic kidney disease (25,26). From a clinical operational standpoint, a low injection rate reduces demands on the power injector and venous access quality, thereby improving examination success rates and applicability. From a technical feasibility standpoint, low-keV monochromatic reconstruction (typically 40–60 keV) amplifies the signal from even trace amounts of iodine via the photoelectric effect, theoretically providing sufficient redundancy for extremely low-injection-rate

protocols. Thus, systematic evaluation of the feasibility of a low-injection-rate spectral CTA protocol for BA imaging has both clinical safety value and technical exploratory significance.

We successfully visualized 253 BAs (125 left, 128 right) in 109 patients and characterized their anatomical features, branching patterns, and courses. This indicates that our low-rate, spectral CTA protocol sufficiently meets clinical requirements for BA anatomical assessment.

Accurate BA anatomical evaluation has multiple clinical applications. In interventional treatment for hemoptysis, BAE is an effective treatment for massive hemoptysis. Preprocedural identification of the origin, number, course, and presence of dangerous anastomoses (e.g., common trunk with the anterior spinal artery) is crucial for procedural success and avoidance of serious complications such as paraplegia. The 44-keV images provided by our protocol clearly depict these details, serving as a reliable “vascular map” for interventionalists. In radiotherapy target delineation for lung cancer, accurate delineation of the gross tumor volume (GTV) while sparing surrounding normal tissues is essential. BA visualization helps identify the vascular territory supplying the tumor, particularly for central lung cancer. Clarifying the relationship between BAs and the tumor, trachea, and esophagus facilitates optimization of radiotherapy plans, reducing complications such as radiation esophagitis and tracheal injury.

This study has several limitations. First, the single-center, retrospective design may have introduced selection bias. Second, we did not have a gold-standard comparison with digital subtraction angiography. Third, the sample size was insufficient for subgroup analysis of rare BA anatomic variants. Fourth, we did not perform stratified analyses according to different underlying diseases (e.g., hemoptysis vs. lung cancer). Fifth, the lack of external validation cohort limits the generalizability of our findings. Sixth, interobserver variability for subjective visual scoring, although assessed, may still influence the reproducibility of our results.

CONCLUSION

In conclusion, a low contrast material injection rate (≤3.0 mL/s) spectral CT angiography protocol with reconstruction at approximately 44 keV yields significantly better BA visualization than conventional 60 keV and 70 keV images, as measured by both quantitative (SNR, CNR) and qualitative (subjective scoring) metrics. The optimal CNR energy level for BA imaging under this low-rate protocol is 40–50 keV (mean, 43.62±2.19 keV). Future prospective, multicenter studies with DSA correlation are warranted to validate these findings. Additionally, exploration of other spectral parameters—such as iodine concentration maps and effective atomic number (Z-effective) images—may further enhance the evaluation of BAs and surrounding structures. Comparative studies between low-rate and standard-rate protocols would also help establish the minimum acceptable injection rate for different clinical scenarios.

Declarations

Ethics approval

This study was approved by the Ethics Committee of the Third Affiliated Hospital of Chongqing Medical University (Approval No. 2023-KL-074). The study was conducted in accordance with the Declaration of Helsinki and relevant institutional and national guidelines and regulations.

Consent to Participate

The requirement for written informed consent was waived by the Ethics Committee of the Third Affiliated Hospital of Chongqing Medical University due to the retrospective nature of the study and the use of anonymized data.

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Figures And Figure Legends

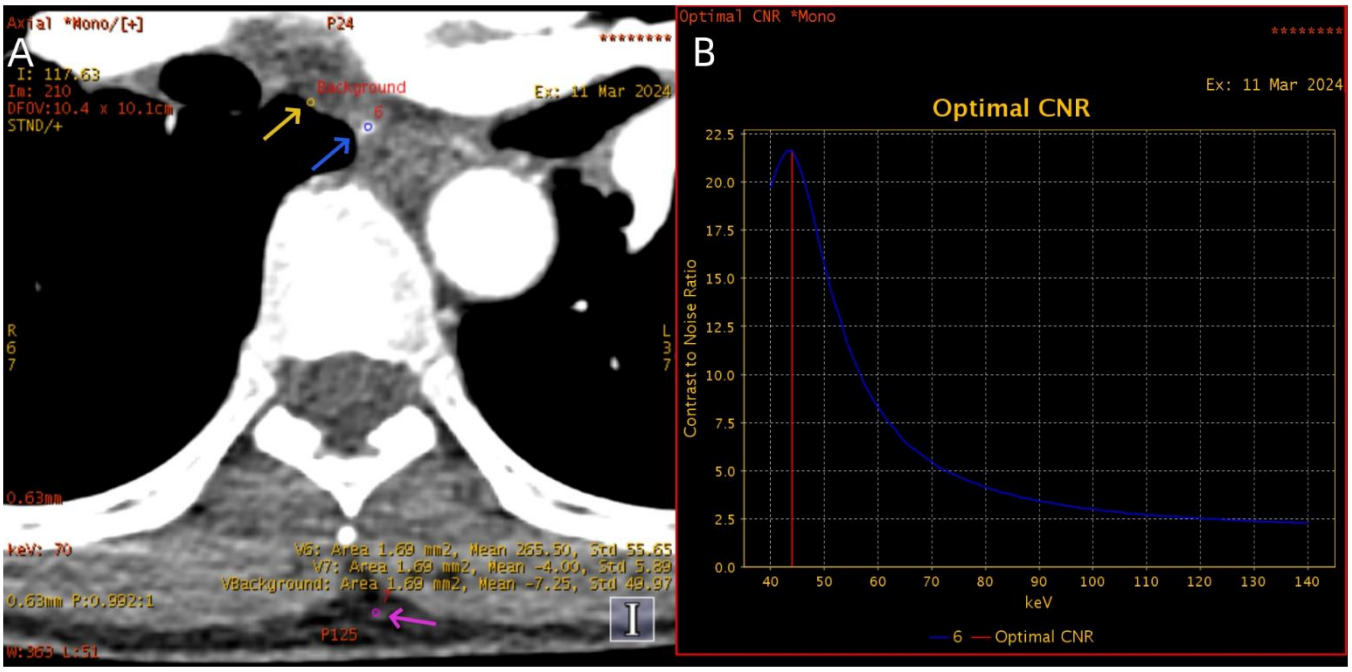


Figure.1. Quantitative analysis of bronchial artery imaging. (A) Axial monochromatic CT image showing regions of interest for quantitative analysis of the bronchial artery (BA). The BA is indicated by a blue arrow, peribronchial interstitial tissue by a yellow arrow, and posterior chest wall subcutaneous fat by a purple arrow. (B) Contrast-to-noise ratio (CNR) curve plotted against monochromatic energy levels, demonstrating that the optimal energy for this patient was 44 keV, at which the highest CNR of the BA was achieved.



Figure.2. Comparison of maximum intensity projection (MIP) images at different monochromatic energy levels. MIP images at the same slice level for the three monochromatic energy groups: 70 keV (A), 60 keV (B), and optimal keV (C). The optimal keV image (C) demonstrates clearer and sharper visualization of the distal bronchial artery (red arrows) compared with the other two energy levels.

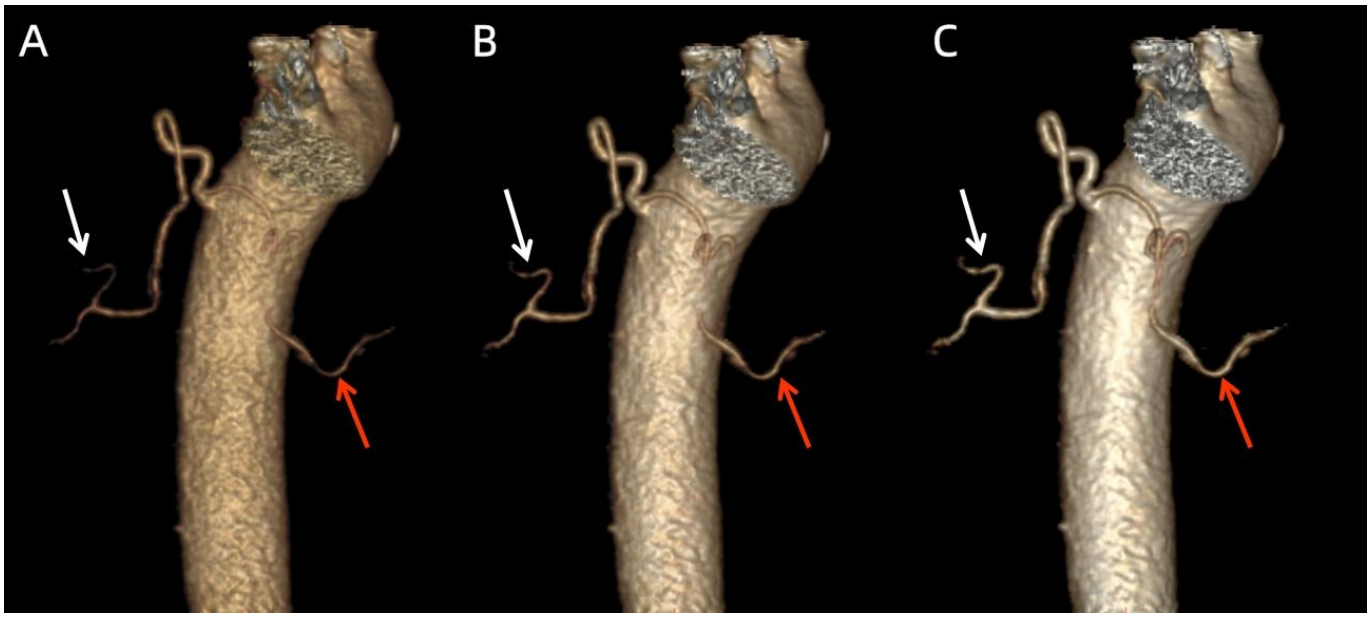


Figure.3. Volume rendering (VR) images of bronchial arteries at three monochromatic energy levels. (A) 70 keV: the distal portions of bilateral bronchial arteries are discernible with acceptable clarity, scored 3 points. (B) 60 keV: the distal margins of bilateral bronchial arteries are clear but not sufficiently sharp, scored 4 points. (C) Optimal keV: bilateral bronchial arteries are clearly visualized with sharp margins, scored 5 points (white arrows indicate the right bronchial artery; red arrows indicate the left bronchial artery).

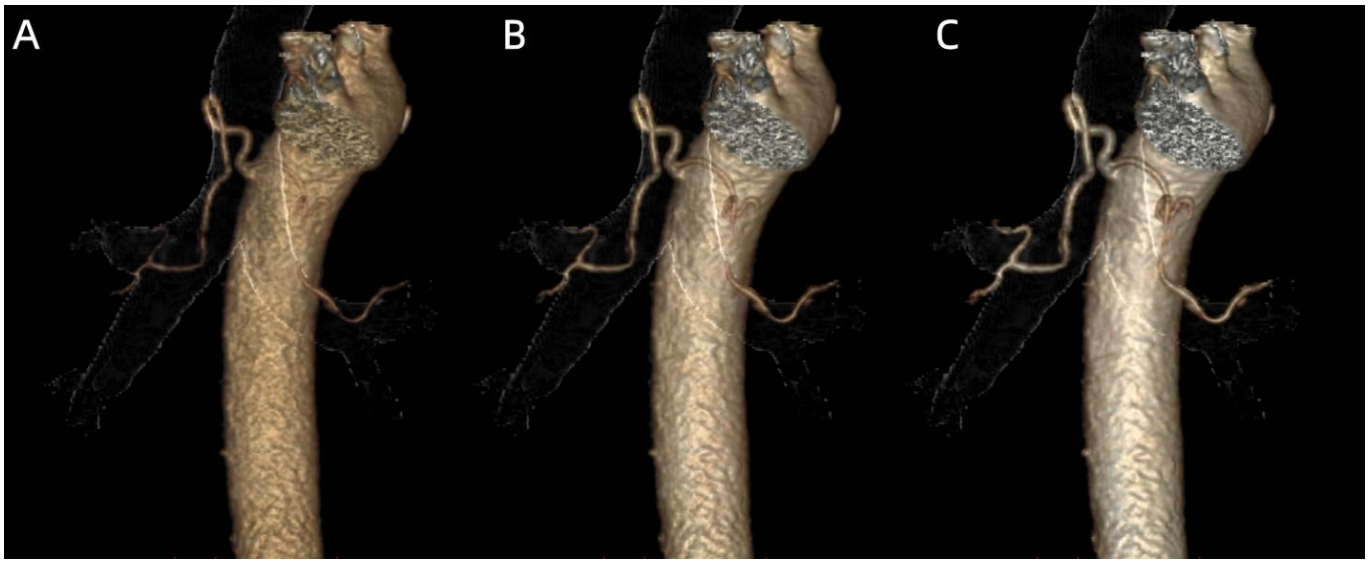


Figure.4. Comparison of fused Volume rendering images of bronchial arteries and bronchi at three monochromatic energy levels. (A) 70 keV, (B) 60 keV, (C) optimal keV. The optimal keV image (C) provides a more intuitive demonstration of the bronchial artery course along the bronchi compared with the other two energy levels.

Table 1. Origin Site and Number of 253 Detected BA in 109 Patients

Origin Site	Left BA Branch No.	Left BA Detection Rate(%)	Right BA Branch No.	Right BA Detection Rate(%)
Descending aorta	115	45.45	42	16.6
Intercostal artery	4	1.58	81	32.01
Aortic arch	5	1.98	4	1.58
Subclavian artery	1	0.4	0	0
Brachiocephalic trunk	0	0	1	0.4
Total	125	49.41	128	50.59

BA,bronchial artery.
Data are raw case counts and corresponding percentage detection rates.
Note: BA arising from common trunk originated at descending aorta are all categorized as descending aorta origin.

Table 2. Anatomical classification and quantity of detected BA in 109 patients (n, %)

Classification	Branch No.	Detection Rate (%)	Classification	Branch No.	Detection Rate (%)
L1	7	6.42	R1	16	14.68
L2	1	0.92	R2	1	0.92

L1R1	44	40.37	R2L1	9	8.26
L2R1	16	14.68	R2L2	10	9.17
L3R2	3	2.75	R3L1	2	1.83

BA,bronchial artery.

Data show branch counts and detection rates for ten BA subtypes.

L1R1 was the dominant type (40.37%), while L2 and R2 had minimal prevalence.

Table 3. Quantitative parameters and subjective image scores of BA images at 70 keV, 60 keV and optimal monoenergetic level (n=109)

Group	BA CT value*(HU)	SNR	CNR	Subjective score
70 keV	224.29±50.73	21.83±14.05	21.61±15.38	2.88±0.84
60 keV	285.42±67.25	22.69±14.67	22.07±15.71	3.62±0.92
Optimal monoenergy	517.46±140.11	24.50±17.22	23.04±16.90	4.19±0.83
P value†	-	<0.05	<0.05	<0.001

BA,bronchial artery;CT,computed tomography;CNR,Contrast-to-Noise Ratio;HU,Hounsfieldunits; SNR,Signal-to-Noise Ratio ;

*No intergroup statistical significance tests were conducted. Data are presented descriptively as mean ± standard deviation, without hypothesis testing for between-group differences.

†*P* value were calculated by performing pairwise comparisons among the three groups, with Bonferroni correction.