

Chest CT with iterative reconstruction algorithms for airway stent evaluation in patients with malignant obstructive tracheobronchial diseases

Tingting Li, MM^a, Yonggao Zhang, MD^{a,*}, Yadong Wang, MM^a, Jianbo Gao, MD^a, Yan Jiang, MD^b

Abstract

The aim of the study was to investigate the image quality of low-dose CT images with different reconstruction algorithms including filtered back projection (FBP), hybrid iterative reconstruction (HIR), and iterative model reconstruction (IMR) algorithms by comparison of routine dose images with FBP reconstruction, in patients with malignant obstructive tracheobronchial diseases.

In total, 60 patients (59 ± 9.3 years, 37 males) with airway stent who are randomly assigned into 2 groups (routine-dose [RD] and low-dose [LD] group, 30 for each) underwent chest CT on a 256-slice CT (RD-group 120 kV, 250 mAs, LD-group 120 kV, 120 mAs). Images were reconstructed with filtered back projection (FBP) algorithm in the RD group, whereas with FBP, HIR and IMR algorithms in the LD group. Effective radiation dose of both groups was recorded. Image-quality assessment was performed by 2 radiologists according to structure demarcation near stents, artifacts, noise, and diagnostic confidence using a 5-point scale (1 [poor] to 5 [excellent]). Image noise and CNR were measured.

The effective radiation dose of LD group was reduced 52.7% compared with the RD group (10.8 mSv ± 0.58 vs 5.1 mSv ± 0.26, $P = 0.00$). LD-IMR images enabled lowest image noise and best subjective image quality scores of all 4 indices, when compared with RD images reconstructed with FBP (RD-FBP) images (all $P < 0.05$). LD images reconstructed with and with HIR (LD-HIR) images enabled higher score in subjective image quality of artifacts ($P < 0.05$), whereas it showed no difference in the other subjective image-quality indices and image noise. Significant higher image noise and lower score of subjective image quality were observed in LD-FBP images (all $P < 0.05$).

Both IMR and HIR improved image quality of low-dose chest CT by comparison of routine dose images reconstructed with FBP. Meanwhile, IMR allows further image quality improvement than HIR.

Abbreviations: AIDR = adaptive iterative dose reduction, ASiR = adaptive statistical iterative reconstruction, BMI = body mass index, CNR = contrast to noise ratio, DLP = dose-length product, ED = effective radiation dose, FBP = filtered back projection, FOV = field of view, HIR = hybrid iterative reconstruction, iDose⁴ = hybrid iterative reconstruction, IMR = iterative model reconstruction, IR = iterative reconstruction, LD group = low-dose group, MDCT = multi-detector computed tomography, RD group = routine-dose group, ROI = region of interest, SAFIRE = Sinogram-affirmed Iterative Reconstruction, SD = standard deviation.

Keywords: airway stent, iterative model reconstruction, low dose, multi-detector computed tomography

1. Introduction

Airway stent placement is increasingly used to treat patients with obstructive tracheobronchial diseases that are caused by malignant tumors such as lung cancer, gastro-esophageal cancer, and thyroid cancer; due to these conditions, patients are often symptomatic and not amenable to surgical resection because of poor clinical status.^[1] However, the complications associated with airway stenting are not uncommon and can occur during the

procedure, shortly after the procedure, or over the long term. In addition, some studies^[2,3] reported that the complication rate is relatively high, especially with long-term use. Multi-detector computed tomography (MDCT), as a highly accurate noninvasive alternative to the reference standard bronchoscopy, plays an important role in evaluation of stent-related complications and is widely used in clinical practice.^[4] Usually, CT scan is performed more than once to provide useful diagnostic information of stent-related complications during the follow-up, but consequently they contribute to a high burden of radiation dose. Therefore, it is valuable to find an approach that can optimize CT protocols to reduce radiation dose while maintaining the image quality and diagnostic accuracy.

Reduced tube current has been investigated as a useful approach to reduce radiation dose; however, it may also accompanied with deteriorated diagnostic quality of CT images due to substantial increases of image noise with a corresponding reduction of CT spatial resolution.^[5] One solution to improve image quality at reduced tube current is the use of iterative reconstruction (IR) algorithms. In the last decade, IR algorithms were introduced to help reduce the quantum noise associated with standard filtered back projection (FBP) reconstruction algorithms.^[6] Previous studies demonstrated that images acquired with hybrid-type IR algorithms such as ASiR for GE, iDose⁴ for Philips, SAFIRE for Siemens, and AIDR for Toshiba

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^aZhengzhou University, Zhengzhou, Henan Province, ^bClinical Science Imaging System, Philips Healthcare, Shanghai, P.R. China.

* Correspondence: Yonggao Zhang, the first affiliated hospital of Zhengzhou University, Zhengzhou, Henan Province, China (e-mail: 13676938925@163.com).

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can maintain image quality with a radiation dose reduction of 23% to 66%, but a certain amount of image noise and artifacts are still present.^[7] Recently, iterative model reconstruction (IMR), a fully iterative algorithm, has been introduced to enable further dose reduction and image-quality improvement in low-dose CT scans,^[8–10] with a knowledge-based approach that yields improved image quality and virtually noise-free images through the iterative minimization of the penalty-based cost function.^[11]

Under the hypothesis that IMR could offer better image quality at low-dose chest CT, we investigated the effect of IMR on the quantitative and qualitative image evaluation by comparing to hybrid IR and FBP images acquired at low doses and FBP images obtained at routine doses.

2. Materials and methods

The prospective study received Institutional Review Board approval; prior informed consent was obtained from all patients.

2.1. Study population

We prospectively enrolled 60 consecutive patients who underwent chest CT between August 2014 and May 2015. All had airway stent placement because of malignant tracheal stenosis resulted by lung or esophageal cancer. The inclusion criteria were (1) body mass index (BMI) not large than 25 kg/m²; (2) metallic stents made of Ni–Ti alloys, considering that this type of metallic stents may cause severe artifacts in low-dose CT images, which especially need improvement. Exclusion criteria included unstable clinical condition, and inability to perform a breath hold.

In the first 5 months, 32 patients underwent chest CT using routine dose protocols (RD group), 2 of them were excluded because of unstable clinical condition. In the second 5 months, 31 patients underwent CT using a low-dose protocol (LD group), and 1 of them was excluded because of large BMI.

2.2. CT acquisition and image reconstruction

All CT examinations were performed on a 256-slice CT scanner (Brilliance iCT; Philips Healthcare, Cleveland, OH), with a scan range from glottis to diaphragm in the cranocaudal direction. The data acquisition parameters were as follows: detector configuration, 128 × 0.625 mm; pitch, 0.99; rotation time, 0.75 s; FOV, 350 mm; slice thickness, 1.0 mm; slice increment, 0.5 mm, matrix 512 × 512; tube voltage, 120 kVp; tube current time products, 250 mAs for the RD group and 120 mAs for the LD group. Images from the RD group were reconstructed with FBP algorithm, whereas images from the LD group were reconstructed with FBP, iDose⁴, and IMR algorithms, respectively. iDose⁴ is a kind of hybrid iterative reconstruction (HIR) algorithm as a routine clinical application in our hospital.

2.3. Image assessment

All images were reviewed and interpreted on a commercially available workstation (Extended Brilliance Workspace, Philips). Objective image assessment was performed by a thoracic radiologist with 5-year experience on reconstructed 1.0 mm thick axial images. A 100 mm² region of interest (ROI) was placed within the ascending aorta at the level of pulmonary trunk bifurcation, the CT value (in Hounsfield units) of the ROI was recorded, and its standard deviation (SD) was used as image

noise. Measurements were performed 3 times and expressed as the mean value.

On the other hand, 2 thoracic radiologists who were not aware of any image reconstruction settings or scan protocols with 3 and 5 years of experience were asked to perform subjective image assessment, independently. The image quality was evaluated according to structure demarcation near stents, artifacts, noise, and diagnostic confidence using a 5-point scale. The scoring details are as follows: (1) sharpness: 1 = unacceptable, 2 = poor sharpness with blurry edge and structure demarcation, 3 = acceptable, the stents and the structure demarcation near stents slightly blurry but without impacting of diagnosis, 4 = better than average, stents and structure demarcation near stents were displayed clear, sharper edge; 5 = excellent, stents and structure demarcation near stents were displayed very clear, sharpest edge; (2) artifacts: 1 = severe unacceptable artifacts, 2 = major artifacts acceptable under limited conditions, 3 = average artifacts not interfering with evaluation of anatomic structure, 4 = slightly artifacts, 5 = optimal or indicated no artifacts; (3) noise: 1 = marked and unacceptable noise; 2 = major but acceptable noise, 3 = average noise, 4 = slightly noise, 5 = indicated free noise; (4) diagnostic confidence, 1 = unacceptable, completely nondiagnostic, 2 = poor, only suggesting lesion, 3 = good, diagnostic, 4 = better, diagnostic confidence, 5 = excellent, fully diagnostic confidence. When the 2 radiologists disagreed, a third thoracic radiologist with >15 years of experience was asked to adjudicate the differences in order to obtain a consensus score.

2.4. Radiation dose management

Total dose-length product (DLP) that represented the total absorbed dose for all the scans were recorded from CT's dose report. Estimated effective dose (ED) was calculated from DLP using a revised normalized effective dose constant of 0.014.^[12]

2.5. Statistical analysis

All continuous values were expressed as mean ± standard deviation (SD). To compare the invariable relationships of the patients demographic and dose measurements between groups, we used the χ^2 test when the predictor was categorical and independent *t* test when the predictor was quantitative. The quantitative image noise was compared with ANOVA analysis, and if there was a significant difference, pairwise comparisons would be performed with the Dunnett test. The qualitative scores were compared by using the Friedman test, and if there was a significant difference, pairwise comparisons would be performed with the Steel–Dwass test. Inter-observer agreement for subjective image scores was measured using the kappa test. All statistical analyses were performed with commercially available software (SPSS Version 22.0 and MedCal 15.2). A value of $P < 0.05$ was considered a statistical significant difference.

3. Results

3.1. Patient demographics and radiation dose

The results of patient demographics and radiation dose are summarized in Table 1. There was no significant difference between the 2 groups with respect to age, gender, body weight, body mass index, and scan length. The DLP and effective dose of LD group were significantly reduced compared to the RD group.

Table 1
Comparisons of patient characteristics and radiation doses between groups.

Characteristics	RD group	LD group	P
Age, y, mean ± SD (range)	60.2 ± 7.2 (42–77)	57.0 ± 9.5 (47–74)	0.09
Men/Women, n/n	20/10	22/8	0.57
Body weight, kg, mean ± SD	56.3 ± 11.0	57.8 ± 11.2	0.60
Body mass index, kg/m ² , Mean ± SD	19.9 ± 3.0	20.3 ± 3.2	0.62
Scan length, cm, mean ± SD	42.4 ± 2.3	42.2 ± 2.2	0.73
DLP, mGy*cm, mean ± SD	717.8 ± 39.0	340.8 ± 17.6	0.00
Effective dose, mSv, mean ± SD	10.8 ± 0.58	5.1 ± 0.26	0.00

DLP = dose-length product.
P < 0.05 as significant difference.

3.2. Objective image assessment

The mean image noise was 14.7HU ± 3.4 on RD images reconstructed with FBP (RD-FBP) images, and 36.2HU ± 7.3, 15.6HU ± 4.5, 5.2HU ± 1.4 on LD-FBP, LD images reconstructed with and with HIR (LD-HIR), and LD-IMR images, respectively. When compared to RD-FBP images as a reference, LD-IMR images enabled significant lower noise (P = 0.00), LD-HIR images showed no significant difference in noise (P = 0.82), and LD-FBP images demonstrated significant higher noise (P = 0.00). Details are demonstrated in Fig. 1.

3.3. Subjective image assessment

There was no significant disagreement between the 2 radiologists (κ = 0.82–0.92). All the qualitative image assessment score for each algorithm of both groups are summarized in Table 2 and Fig. 2. Similar to objective results, when compared to RD-FBP images, LD-IMR images enabled significant higher score in all the indices including sharpness, artifacts, noise, and diagnostic confidence; however, LD-HIR images showed no significant difference in sharpness, noise, and diagnostic confidence, but a higher score in artifacts; LD-FBP images demonstrated significant lower score in all indices and failed to acquired diagnostic acceptable image quality.

4. Discussion

To our knowledge, HIR has been investigated to compensate for the increased noise at low-dose CT scans during decade. However, a certain amount of image noise and some artifacts continue to be present due to its inherent approach.^[13–15] Unlike HIR, IMR is an advanced iterative reconstruction that applies a knowledge-based approach to accurately determine the data and

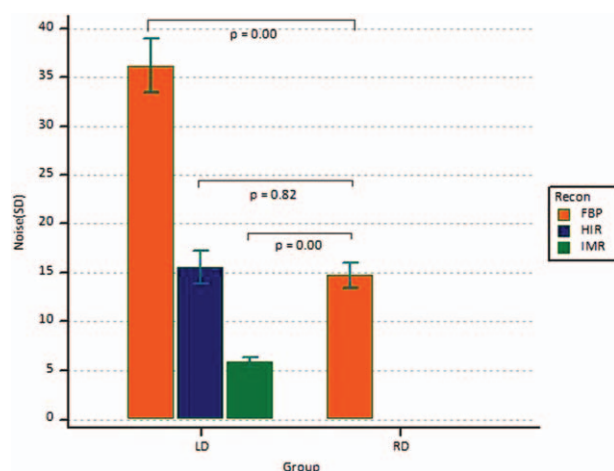


Figure 1. Comparison of image noise among images with different reconstruction algorithms in different dose groups. No significant difference was found between LD-HIR and RD-FBP images. LD-HIR = LD images reconstructed with and with HIR; RD-FBP = RD images reconstructed with FBP.

image statistical models that are coupled with the model of the CT system and involve the geometry and physical characteristics of the CT scanner.^[16] It is mathematically more complex and accurate, and theoretically enables lower image noise and better image quality. Consistent with the theory, our results revealed that IMR significantly improved both objective and subjective image quality at LD chest scans using < 50% of routine tube current (Figs. 3–6). As compared to the reference of RD-FBP images, IMR yielded LD images of better subjective image quality of sharpness, artifacts, noise and diagnostic confidence, and significantly reduced image noise, whereas HIR yielded LD images of diagnostic acceptable quality and higher image quality score of artifacts compared to RD-FBP images. This observation is of practical importance because 50% low-dose chest CT with both IR algorithms are able to help reduce the risk of radiation exposure without compromising the quality of diagnostic information in patients with airway stent to repeated chest CT for evaluation of stent-related complications.

Unlike previous low-dose chest CT studies, our study is the first clinical study of IR application focusing on airway stent evaluation in patients with malignant tracheobronchial stenosis. Previous studies^[8,17–19] indicated that HIR was able to yield diagnostic image quality at around 1 mSv, IMR was able to yield sub-mSv chest CT scans without compromising image quality. However, relatively high radiation dose acquired in our study is

Table 2
Subjective scores of image quality according to reconstruction method.

	RD group		LD group						kappa value
	FBP		FBP		HIR		IMR		
	Reader1	Reader 2	Reader1	Reader2	Reader1	Reader 2	Reader1	Reader 2	
Sharpness	0/0/15/12/3	0/0/13/13/4	3/3/21/3/0	2/4/22/2/0	0/0/9/20/1	0/0/8/20/2	0/0/2/16/12	0/0/1/15/14	0.824
Artifacts	0/1/19/10/0	0/1/17/11/1	2/8/17/3/0	3/8/16/3/0	0/1/11/15/3	0/1/10/15/4	0/0/2/14/14	0/0/1/14/15	0.892
Noise	0/1/9/18/2	0/1/8/18/3	0/9/20/1/0	0/10/10/0/0	0/1/13/17/0	0/0/12/16/2	0/0/0/9/21	0/0/0/8/22	0.887
Diagnostic confidence	0/0/13/14/3	0/0/11/15/4	1/6/20/3/0	0/7/21/2/0	0/0/8/15/7	0/0/7/16/7	0/0/0/10/20	0/0/0/9/21	0.921

Data show the frequency of numerical scores given in each category (grade 1/2/3/4/5).
FBP = filtered back projection, HIR = hybrid iterative reconstruction, IMR = iterative model reconstruction, LD group = low-dose group, RD group = routine-dose group.

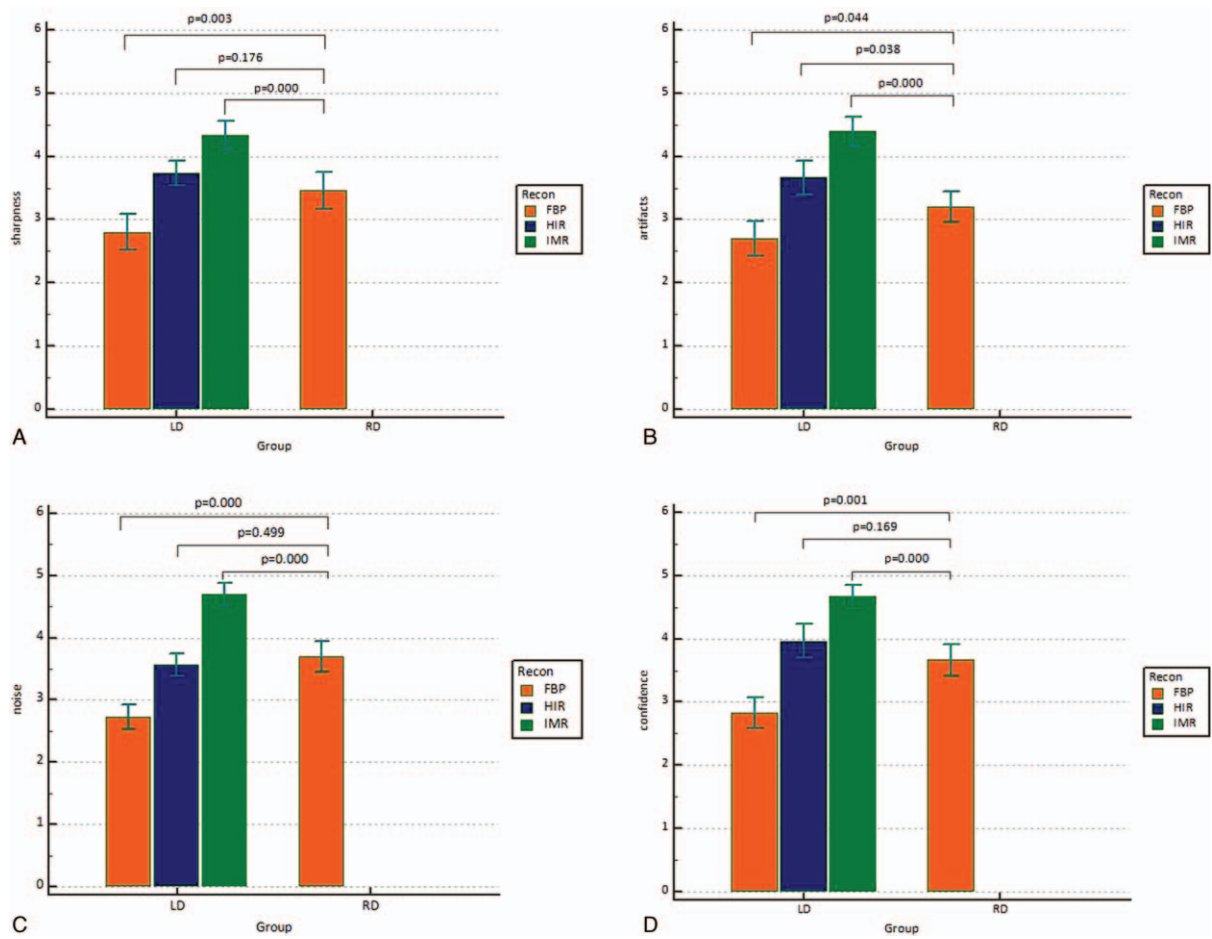


Figure 2. Comparison of subjective image quality score with different reconstruction algorithms in different dose groups: (A) sharpness; (B) artifacts; (C) noise; (D) diagnostic confidence. LD-FBP images failed in acceptable image quality of all indices (score ≤ 3). $P < 0.05$ was considered as a statistical significant difference.

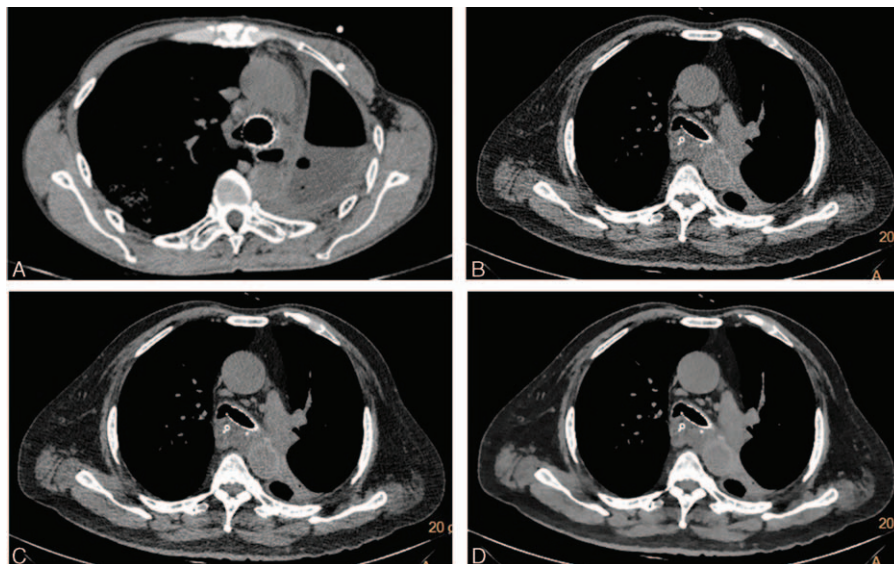


Figure 3. Axial CT images of airway stent of a 59-year-old male (body mass index, 21.3) (RD group) (A) and 63-year-old male (body mass index, 24.9) (LD group) (B–D) with malignant tracheobronchial stenosis. LD images reconstructed with IMR (D) showed best subjective image quality and lowest image noise. LD images reconstructed with HIR (C) showed similar image quality compared to RD images reconstructed with FBP (A). LD images reconstructed with FBP (B) showed significant increased noise. CT = computed tomography, FBP = filtered back projection, HIR = hybrid iterative reconstruction, IMR = iterative model reconstruction, LD group = low-dose group, RD group = routine-dose group.

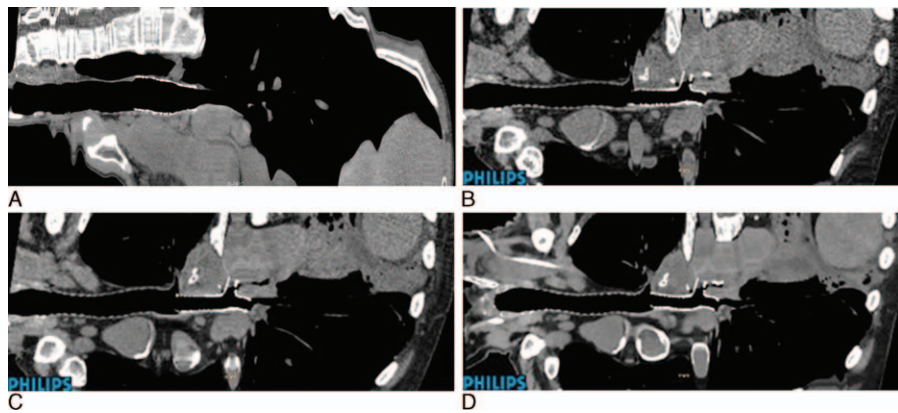


Figure 4. Curve planar reconstruction images of airway stent of a 59-year-old male (body mass index, 21.3) (RD group) (A) and 63-year-old male (body mass index, 24.9) (LD group) (B–D) with malignant tracheobronchial stenosis. LD images reconstructed with FBP (B) showed significant increased noise as well as artifacts surrounding the stent. LD images reconstructed with HIR (C) showed certain artifacts reduction, LD images reconstructed with IMR (D) showed better artifacts reduction than HIR. FBP = filtered back projection, HIR = hybrid iterative reconstruction, IMR = iterative model reconstruction, LD group = low-dose group, RD group = routine-dose group.

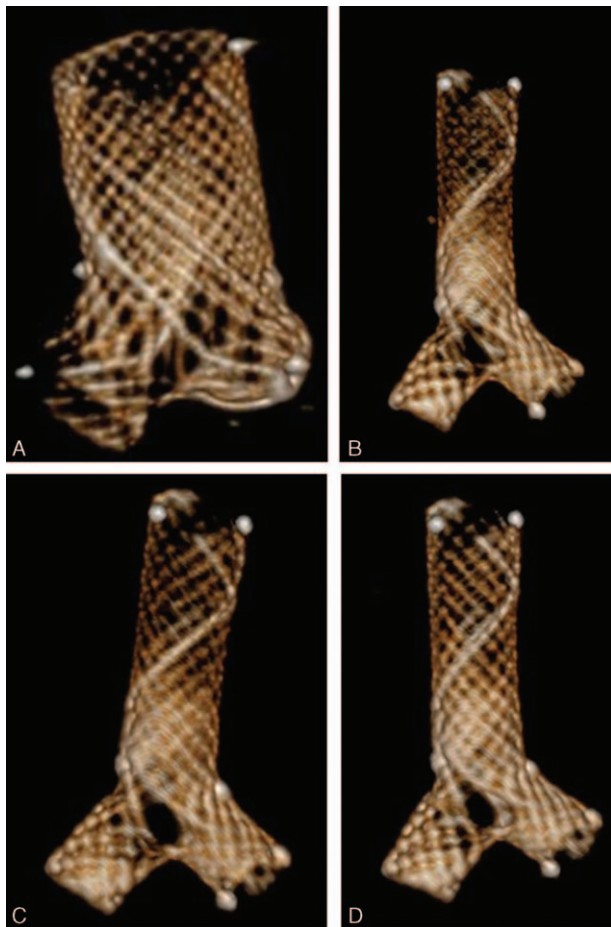


Figure 5. Volume-rendered images of airway stent of a 59-year-old male (body mass index, 21.3) (RD group) (A) and 63-year-old male (body mass index, 24.9) (LD group) (B–D) with malignant tracheobronchial stenosis. LD images reconstructed with IMR (D) helped improve the detail display of stent texture. LD images reconstructed with HIR (C) showed similar image quality compared to RD images reconstructed with FBP (A). LD images reconstructed with FBP (B) showed increased noise and loss of partial detail of stent texture. FBP = filtered back projection, HIR = hybrid iterative reconstruction, IMR = iterative model reconstruction, LD group = low-dose group, RD group = routine-dose group.

resulted by relatively conservative dose reduction protocol with large scan range. First, the scan range is from the level of glottis to diaphragm, considering that the vocal cords are needed to display as a marker to locate the airway stents. Second, it is of importance to display mediastinal structure clearly to evaluate stent-related complications such as stent malposition, stent migration, granulation tissue formation, tumor ingrowth, mucoid impaction, infection, and stent fracture. Thus, relatively conservative dose reduction protocol with a routine tube voltage (120 kV) was performed to ensure acceptable image quality of mediastinal structure and to avoid increased artifacts caused by metal stent itself due to photon starvation and beam hardening effects.

Nevertheless, IMR-enabled superior and significant better image quality as well as HIR-enabled slightly better image quality as compared to RD-FBP images indicated that there is great potential to reduce radiation dose further for chest CT of airway stent evaluation. In addition, it is worth noting that both IMR and HIR were observed to reduce artifacts caused by metal stents, and IMR-enabled best quality score of artifacts, which is similar to the result of previous study in evaluation of prosthetic heart valve-related artifacts.^[20]

Our study has several limitations. First, IMR and HIR images were not reconstructed from the RD group, only 4 series were compared, with RD-FBP images as reference. IMR, HIR, and FBP images can be reconstructed from both LD and RD groups in further study, and all 6 series comparison can be performed to provide more complete view. Second, our study adopted a relatively conservative dose reduction protocol; however, further dose reduction should be achieved in future studies. Third, our study population was relatively small, which may result in some deviations, but it should not influence the study results.

5. Conclusion

In conclusion, both IMR and HIR improved image quality of low-dose chest CT by comparison of routine dose images reconstructed with FBP. Meanwhile, IMR allowed further image-quality improvement than HIR. IMR with significant better image quality may emphasize its potential to better delineate lesion structures around airway stents in patients with malignant tracheal stenosis.

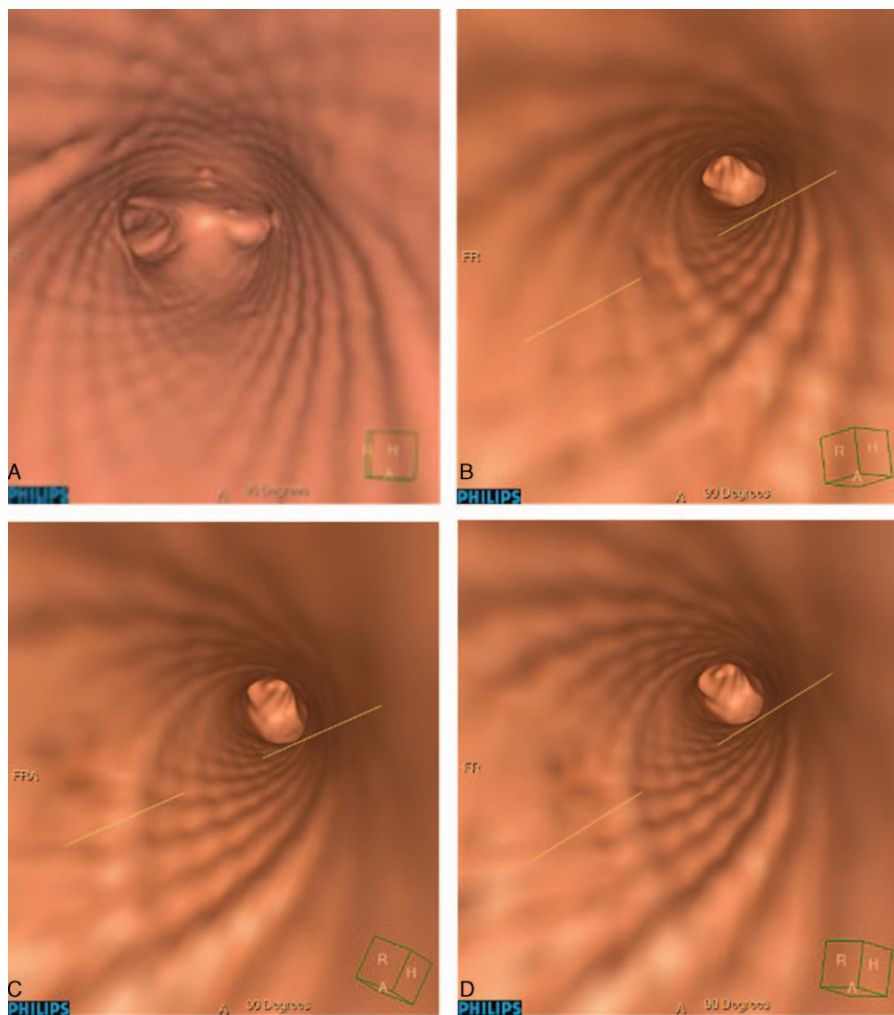


Figure 6. CT virtual bronchoscopy images of airway stent of a 59-year-old male (body mass index, 21.3) (RD group) (A) and 63-year-old male (body mass index, 24.9) (LD group) (B–D) with malignant tracheobronchial stenosis. LD images reconstructed with IMR (D) and with HIR (C) showed similar image quality compared to RD images reconstructed with FBP (A). LD images reconstructed with FBP (B) showed loss of partial detail of stent texture. FBP = filtered back projection, HIR = hybrid iterative reconstruction, IMR = iterative model reconstruction, LD group = low-dose group, RD group = routine-dose group.

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