

Role of Maximum Intensity Projection Technique in Delineating Segmental and Subsegmental Branches of Pulmonary Artery Compared to Multiplanar Recont Technique in Evaluating Pulmonary Embolism

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Received: 15th Feb, 2026; Revised: 27th Feb, 2026; Accepted: 20th Mar, 2026; Available Online: 5th Apr, 2026

ABSTRACT

Background

Computed tomography pulmonary angiography (CTPA) is the gold standard investigation for diagnosing pulmonary embolism (PE). Maximum Intensity Projection (MIP) is an advanced post-processing technique that may enhance the delineation of segmental and subsegmental pulmonary arteries without additional radiation exposure or patient morbidity.

Objective

To assess the diagnostic efficacy of MIP technique in delineating segmental and subsegmental pulmonary arteries in patients with suspected PE, and to compare outcomes with standard Multiplanar Reconstruction (MPR).

Methods

Thirty patients referred for CTPA with suspected PE were prospectively included. Images were reconstructed using both MIP and MPR techniques. Quantitative analysis assessed the proportion of analyzable segmental and subsegmental arteries in each lung. Subjective image quality was evaluated using a 4-point Likert scale. Statistical comparisons were performed using the chi-square test and Mann-Whitney U test.

Results

The mean age of patients is 54.1 ± 19.9 years. In the right lung, 66.7% of branches were analyzable with MIP which is only 53.3% with MPR. In the left lung, 60.0% were analyzable with MIP which is 33.3% with MPR ($p = 0.038$). Overall combined analyzability was significantly higher with MIP (63.3% vs 43.3%; $p = 0.028$; RR = 1.46). Subjective image quality assessed by Likert scoring was significantly better with MIP (median 3 [IQR 3–3]) compared to MPR (median 2 [IQR 1–2]; $p < 0.001$).

Conclusion

MIP technique is considered to have better diagnostic efficacy in delineating segmental and subsegmental pulmonary arteries compared to standard MPR, with particular advantage in the left lung. Its integration into routine CTPA reporting is recommended.

Keywords: Pulmonary embolism; Maximum Intensity Projection; CT pulmonary angiography; Multiplanar reconstruction; Image quality; Vascular delineation

How to cite this article: Sundararajan MG, Santhana Lakshmi KS, Sathyanarayanan. Role of Maximum Intensity Projection Technique in Delineating Segmental and Subsegmental Branches of Pulmonary Artery Compared to Multiplanar Recont Technique in Evaluating Pulmonary Embolism. *Int J Drug Deliv Technol.* 2026;16(4): 232-237. DOI: 10.25258/ijddt.16.4.26

Source of support: Nil.

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Conflict of interest: None

1. INTRODUCTION

Pulmonary embolism (PE) is a life-threatening cardiovascular emergency resulting from obstruction of the pulmonary arterial circulation, most commonly by thromboembolism arising from deep vein thrombosis (DVT) of the lower extremities. Acute venous thromboembolism (VTE), encompassing DVT and PE, is ranked as the third leading cause of cardiovascular mortality after myocardial infarction and stroke, with an annual incidence of 1–2 events per 1,000 individuals in Western populations [1]

Computed tomography pulmonary angiography (CTPA) has emerged as the gold standard diagnostic modality for PE, owing to its wide availability, rapid acquisition, and multiplanar capability [2]. However, accurate characterization of emboli in segmental and subsegmental branches remains challenging due to vessel caliber, respiratory motion artifacts, and variable enhancement. Subsegmental PE constitutes up to 5–10% of all diagnosed PE, and its clinical management remains controversial, requiring precise imaging delineation for sound therapeutic decision-making [3].

Maximum Intensity Projection (MIP) is a volume rendering post-processing technique that projects the voxel of maximum attenuation encountered along rays cast through a three-dimensional dataset, generating two-dimensional images that preferentially display high-density structures such as contrast-opacified blood vessels [4]. In 1988 Wallis first described MIP for nuclear medicine applications and then it has been used extensively in CT angiography [5]. Unlike Shaded Surface Display (SSD), MIP retains full attenuation information and offers superior small vessel visualization with minimal additional post-processing burden as it does not rely on a fixed threshold [6].

Despite its theoretical advantages, MIP remains incompletely integrated into standard CTPA reporting workflows, partly due to a paucity of rigorous comparative data against established reconstruction methods. Multiplanar Reconstruction (MPR), which reslices the original isotropic dataset in coronal, sagittal, and oblique planes, constitutes the conventional adjunct to axial imaging in CTPA interpretation. While MPR provides accurate anatomical localization, it does not inherently enhance vessel conspicuity as MIP does.

Hence, our study is done to evaluate and compare the diagnostic performance of MIP and MPR techniques in delineating segmental and subsegmental pulmonary arteries using both quantitative (analyzability assessment) and qualitative (Likert-scale image quality scoring) analysis in a cohort of patients undergoing CTPA for suspected PE.

2. MATERIALS AND METHODS

2.1 Study Design and Patient Population

It is a prospective observational study conducted in the Department of Radiodiagnosis at a teaching medical college and hospital. Thirty consecutive patients referred for CTPA by a pulmonologist for suspected PE during the study period were enrolled. The study was initiated only after approval by the Ethics Committee. Written and informed consent was obtained from all participants.

Inclusion criteria were: (a) clinical suspicion of PE based on a pulmonologist's assessment; (b) indication for CTPA; and (c) age 18–70 years. Exclusion criteria included: known allergy to iodinated contrast media, pregnancy, renal impairment (eGFR < 30 mL/min/1.73 m²), severe respiratory conditions preventing breath-hold, and the presence of implants incompatible with imaging equipment.

2.2 CT Acquisition Protocol

All examinations were done using a Philips Ingenuity 128-slice CT scanner. Imaging proceeded craniocaudally from the lung apices to the bases during a single breath-hold. Non-ionic intravenous contrast material (100 mL Iopromide, Ultravist 370, Bayer AG, Germany) was given at a flow rate of 4 mL/s through 20gauge antecubital venous cannula via a dual-head power injector, followed by a 20 mL normal saline flush. Bolus tracking with a threshold of 100 Hounsfield Units (HU) in the main pulmonary artery was employed for scan triggering. Images were reconstructed at 1 mm slice thickness and 0.5 mm reconstruction increment. The field of view encompassed the entire thoracic region. All scans were reviewed at a lung window setting (window level: –600 HU; window width: 1500 HU).

2.3 Image Post-Processing

Reconstructed axial CTPA datasets were transferred to a dedicated workstation (Philips IntelliSpace Portal). For each patient, both MIP and MPR image sets were independently generated. MIP images were created using thin-slab MIP with 8 mm slab thickness reconstructed in

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axial, coronal, and sagittal planes. MPR images were generated in standard coronal and sagittal planes from the original isotropic dataset. Both reconstructions were evaluated independently by two experienced radiologists blinded to each other's assessments.

2.4 Outcome Measures

Two complementary analytical approaches were employed:

Quantitative Analysis: Each segmental and subsegmental artery was categorized as 'analyzable' (adequate opacification and delineation permitting confident diagnosis) or 'non-analyzable' (inadequate visualization precluding diagnostic assessment) for both MIP and MPR reconstructions, separately for the right and left lungs.

Qualitative Analysis: Subjective image quality was independently scored using a validated 4-point Likert scale: Grade 1 = non-diagnostic; Grade 2 = diagnostic; Grade 3 = good; Grade 4 = excellent. A score of ≥ 2 was considered diagnostically acceptable.

2.5 Statistical Analysis

Statistical analysis was performed using SPSS version 25.0 (IBM Corp). Continuous data are reported as mean \pm standard deviation (SD). Categorical data are expressed as frequencies and percentages. The chi-square test was applied to compare proportions of analyzable vessels between MIP and MPR for individual lungs and overall. Relative risk (RR) with 95% confidence intervals was calculated. Since Likert scores represent ordinal data, between-group comparisons were performed using the Mann-Whitney U test. Data are reported as median with interquartile range (IQR). A p-value of less than 0.05 was considered significant Statistically.

3. RESULTS

3.1 Patient Demographics

The mean age of study participants was 54.1 ± 19.9 years (range: 18–85 years). The gender distribution comprised 16 males (53.3%) and 14 females (46.7%), with no statistically significant difference between groups ($p > 0.05$). Demographic data are summarized in Table 1.

Table 1. Demographic detail of the study participants (n = 30)

Variable	Value
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Total number of patients (n)	30
Mean age \pm SD (years)	54.1 ± 19.9
Age range (years)	18 – 85
Male, n (%)	16 (53.3%)
Female, n (%)	14 (46.7%)

3.2 Quantitative Analysis: Analyzability of Pulmonary Arterial Branches

In the right lung, 66.7% (n = 20/30) of segmental and subsegmental arteries were analyzable using MIP compared with 53.3% (n = 16/30) using MPR which is not statistically significant ($\chi^2 = 1.11$; $p = 0.292$). In the left lung, MIP demonstrated significantly superior analyzability: 60.0% (n = 18/30) versus 33.3% (n = 10/30) with MPR ($\chi^2 = 4.29$; $p = 0.038$). When data from both lungs were pooled (total assessment units = 60 per technique), MIP showed overall analyzability of 63.3% (n = 38/60) compared with 43.3% (n = 26/60) for MPR ($\chi^2 = 4.82$; $p = 0.028$; RR = 1.46, 95% CI: 1.04–2.04). Results are detailed in Table 2.

Table 2. Quantitative analysis of analyzable segmental and subsegmental arterial branches.

Lung Region	MIP Analyzable (%)	MPR Analyzable (%)	χ^2 value	p-value
Right Lung	66.7% (20/30)	53.3% (16/30)	1.11	0.292
Left Lung	60.0% (18/30)	33.3% (10/30)	4.29	0.038 *
Combined (both lungs)	63.3% (38/60)	43.3% (26/60)	4.82	0.028 *

*Statistically significant ($p < 0.05$); RR (combined) = 1.46 (95% CI: 1.04–2.04)

3.3 Qualitative Analysis: Subjective Image Quality

Likert-scale scoring revealed markedly superior image quality with MIP across all diagnostic grades. With MIP, no images were rated non-diagnostic (Grade 1 = 0%), while 13.3% (n = 4) were diagnostic (Grade 2), 66.7% (n = 20) were good (Grade 3), and 20.0% (n = 6) were excellent (Grade 4). In contrast, with MPR, 30.0% (n =

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9) of images were non-diagnostic, 50.0% (n = 15) were diagnostic, 16.7% (n = 5) were good, and 3.3% (n = 1) were excellent. The median Likert score was significantly higher for MIP (median 3.0, IQR 3.0–3.0) compared with MPR (median 2.0, IQR 1.0–2.0; Mann-Whitney U = 773.0; p < 0.001). Diagnostic acceptability (Likert ≥ 2) was 100% for MIP versus 70.0% for MPR. Results are presented in Table 3.

Table 3. Qualitative image quality analysis using 4-point Likert scale.

Likert Grade	MIP n (%)	MPR n (%)
Grade 1 (Non-diagnostic)	0 (0.0%)	9 (30.0%)
Grade 2 (Diagnostic)	4 (13.3%)	15 (50.0%)
Grade 3 (Good)	20 (66.7%)	5 (16.7%)
Grade 4 (Excellent)	6 (20.0%)	1 (3.3%)
Median score (IQR)	3.0 (3.0–3.0)	2.0 (1.0–2.0)
Diagnostically acceptable (≥2)	30 (100%)	21 (70.0%)

Mann-Whitney U = 773.0; p < 0.001

Table 4. Summary of statistical analyses

Statistic	Comparison	Test Statistic	p-value	Effect
Chi-square	Right lung analyzability	$\chi^2 = 1.11$	0.292	NS
Chi-square	Left lung analyzability	$\chi^2 = 4.29$	0.038 *	RR=1.80
Chi-square	Combined analyzability	$\chi^2 = 4.82$	0.028 *	RR=1.46

Mann-Whitney U	Likert image quality	U = 773.0	< 0.001 **	Large
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NS = Not significant; *p < 0.05; **p < 0.001

4. DISCUSSION

Our study systematically compared the diagnostic efficacy of MIP post-processing against standard MPR reconstruction in a CTPA cohort of 30 patients with suspected PE. The principal findings were: (i) MIP demonstrated significantly superior overall analyzability of segmental and subsegmental pulmonary arterial branches compared with MPR (63.3% vs. 43.3%; p = 0.028); (ii) this advantage was most pronounced in the left lung (60.0% vs. 33.3%; p = 0.038); and (iii) MIP yielded markedly superior subjective image quality scores, with 100% diagnostic acceptability versus 70% for MPR (p < 0.001).

These findings are concordant with the established physical principles underlying MIP. By projecting the maximum attenuation voxel encountered along each ray path, MIP exploits the high CT number of iodinated contrast within patent pulmonary vessels relative to surrounding parenchyma, cardiac structures, and mediastinal fat, thereby enhancing vessel conspicuity. This projection-based approach enhances the visibility of even small peripheral vessels that are often difficult to follow on individual axial slices or standard orthogonal multiplanar reformations (MPR). In contrast, conventional MPR techniques merely rearrange the original voxel data into different planes without improving the inherent contrast.

Prokop et al. in a seminal review on MIP in CT angiography similarly showed that MIP is particularly effective only for illustrating small vessels, though cautioned that its inability to distinguish foreground from background structures requires careful interpretation, ideally with concurrent review of the source axial dataset [7]. Our findings show that MIP has more advantage for small-vessel visualization in the pulmonary vascular territory which shows that it is statistically significant in the left lung (p = 0.038) but non-significant trend in the right lung (p = 0.292) may reflect the smaller caliber and more complex angulation of left pulmonary segmental branches, which would be expected to benefit disproportionately from the enhanced vessel conspicuity afforded by MIP.

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Napel et al. introduced the sliding thin-slab MIP (STS-MIP) technique and demonstrated improved delineation of pulmonary vessels and airways, with preservation of excellent contrast resolution across thin-section CT images, an observation replicated in our study through the consistently higher Likert grades assigned to MIP images [8]. Furthermore, Kawel et al. reported that MIP with 8 mm slab thickness achieved high sensitivity for small pulmonary nodule detection, with MIP specifically outperforming MPR for lesions smaller than 7 mm, suggesting that enhanced small-structure conspicuity is a generalizable advantage of the technique. Our study extends this principle to the vascular domain which demonstrates the superior delineation of subsegmental arterial branches.

The lack of non-diagnostic MIP images (Grade 1 = 0%) is in contrast with MPR non-diagnostic rate of 30%, with a corresponding relative risk for MIP analyzability of 1.46. This is important because in a disease state in which failure to diagnose emboli in the periphery may lead to failure to anticoagulate with potentially lethal consequences, any method that reduces the rate of non-diagnostic imaging is important.

Our study also has some limitations. The small sample size of 30 patients, while adequate for initial hypothesis testing, is relatively modest and may limit statistical power for subgroup analyses, as evidenced by the non-significant right lung comparison despite a 13.4 percentage-point difference. Future larger multicenter studies are needed to confirm and generalise these findings. Additionally, the absence of a reference standard (such as digital subtraction angiography or surgical confirmation) precludes direct calculation of sensitivity and specificity. The study was conducted at a single institution with a single CT scanner model, that limits the generalizability across different acquisition platforms. Finally, inter rater reliability between the two reporting radiologists was assessed, which shows the methodological gap.

5. CONCLUSION

Maximum Intensity Projection post-processing demonstrates shows superiority over standard Multiplanar Reconstruction in the delineation of segmental and subsegmental pulmonary arterial branches on CTPA, which help in achieving higher analyzability rates and good image quality. The technique also eliminates non-diagnostic imaging in all

cases, that confers a relative risk advantage of 1.46 for overall arterial analyzability, and requires no additional radiation exposure or contrast administration. These findings support the integration of MIP as a routine adjunct to standard axial and MPR review in CTPA reporting protocols for suspected pulmonary embolism.

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