MDCT Angiography of the Pulmonary Arteries: Influence of Iodine Flow Concentration on Vessel Attenuation and Visualization

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OBJECTIVE. Our objective was to assess the influence of iodine flow concentration on attenuation and visualization of the pulmonary arteries in thoracic MDCT angiography.

MATERIALS AND METHODS. One hundred consecutive patients who were referred to our department with suspected acute pulmonary embolism underwent MDCT angiography of the pulmonary arteries either with 120 mL of standard contrast medium (300 mg I/mL) (group A) or with 90 mL of high-concentration contrast medium (400 mg I/mL) (group B). The contrast medium was injected at a flow rate of 4 mL/sec. The scan delay was determined using a semiautomatic bolus-tracking system in all examinations conducted with the same scanning parameters. Quantitative analysis was performed by region-of-interest measurements along the z-axis to compare the attenuation profiles of the two groups. Attenuation of the fourth-, fifth-, and sixth-order arteries was assessed visually for differences between the two groups.

RESULTS. The mean enhancement along the z-axis was 268 ± 56 H in group A and 344 ± 108 in group B. The difference of 76 H was statistically significant (p < 0.001). The attenuation profile was similar in both groups. The detection rate of fifth- and sixth-order arteries was significantly higher in group B than in group A (94% compared with 91% and 72% compared with 60%, respectively, p < 0.01).

CONCLUSION. Use of a high flow concentration of iodine in MDCT angiography of the pulmonary arteries significantly increases attenuation of the pulmonary arteries, thereby improving visualization of subsegmental pulmonary arteries.

Helical CT angiography (CTA) of the pulmonary arteries has gained an important role in the diagnosis of patients with suspected pulmonary embolism [1–8]. Sensitivity at the level of the subsegmental pulmonary arteries has been a limitation of single-detector CTA [6]. The development of MDCT angiography led to improved depiction of subsegmental pulmonary arteries due to faster scanning at thinner collimation over a larger scanning volume [9–12]. Aside from fast-scanning technique and thin collimation, optimal arterial attenuation remains one of the most crucial determinants of sufficient depiction of the pulmonary arteries. Arterial attenuation over time is generally determined by iodine flow concentration, which may be increased by raising the contrast flow rate or by using a contrast medium with a high iodine concentration [13].

This study tested two hypotheses. The first was that an increased flow concentration of iodine improves attenuation of the pulmonary arteries. The second was that visualization of subsegmental pulmonary arteries might be improved in MDCT angiography of the pulmonary arteries.

Materials and Methods

Patient Population

One hundred consecutive patients who were referred to our department with suspected acute pulmonary embolism underwent MDCT angiography of the pulmonary arteries either with standard contrast medium (group A) or with high-concentration contrast medium (group B). Patient demographics and characteristics are listed in Table 1. One patient underwent CTA initially with standard contrast medium and in a follow-up examination with high-concentration contrast medium.

Acquisition Protocol

In group A, MDCT angiography of the pulmonary arteries was performed with 120 mL of standard contrast medium (iopromide [Ultravist], 300 mg I/mL, Schering) administered at a flow rate of 4 mL/sec, whereas in group B 90 mL of high-concentration contrast medium was injected (iomeprol [Iomeron], 400 mg I/mL, Bracco) at the same...
flow rate. Both groups received a total iodine dose of 36 g. The scan delay was estimated using a semiautomatic bolus-tracking system (SmartPrep, GE Healthcare) with a threshold of 80 H in all examinations. Regions of interest (ROIs) for bolus tracking were set in the right atrium. All scans were initiated manually after a breathing command with a gap of 3 sec between manual initiation of the scan and the beginning of the scan. The mean scan delay was 14.5 ± 2.8 sec for group A and 15.1 ± 2.3 sec for group B. Before the contrast medium was administered, saline injections were manually administered with the patient’s arm in scanning position to ensure successful cannulation of the vein. After administration of the contrast bolus, a saline solution flush of 40 mL was administered using a double-syringe power injector (Missouri CT-Injector XD 2001, Ulrich). Scanning was performed with an MDCT scanner (LightSpeed QXi, GE Healthcare) with four detector arrays. The scans were obtained with a detector configuration of 1.25 mm, a pitch of 1.5 (high-speed mode), a reconstruction increment of 0.8 mm, and a section thickness of 1.25 mm. The gantry rotation time was 0.8 sec. All scanning was caudal to cranial from the dome of the diaphragm to the apex of the lung. The mean scanning time was 19.5 ± 2.9 sec for group A and 20.6 ± 3.2 sec for group B. The mean scanning range was 17.4 ± 2.7 cm for group A and 18.3 ± 2.5 cm for group B. An X-ray tube voltage of 120 kV and a current of 230–250 mA were used in all examinations.

### Image Analysis

All CT scans were loaded on a workstation (MagicView, Siemens). Quantitative analysis was performed by ROI measurements along the z-axis. The following arteries were measured: subsegmental and segmental arteries of the lower lobes, lobular arteries, main pulmonary arteries, upper lobe arteries, and segmental and subsegmental arteries of the upper lobes. When more measurements were obtained per table position (e.g., subsegmental and segmental level in the upper and lower lobes), the measurements were averaged. The distance between the measurements was 1.2 cm. An attempt was made to maintain an ROI including nearly the whole vessel diameter and to localize the ROI in areas without artifacts. For each measurement, the mean attenuation was recorded. In addition, the diameter of the pulmonary trunk was recorded. All measurements were performed by one observer, who was unaware of the patient’s group.

Visual analysis was performed by four radiologists. Consensus interpretation was performed by at least two reviewers, who scored peripheral arteries as visualized or not visualized. An artery was considered visualized when contrast enhancement was detected from the proximal to the distal portion of the artery. The arteries were named according to the nomenclature of Remy-Jardin et al., as described by Boyden [14], and according to the nomenclature of Jackson and Huber [15]. Twenty segmental (third-order) and 40 subsegmental (fourth-order) arteries are described in this nomenclature. The fifth-order arteries were recognized as dichotomous divisions of the corresponding subsegmental branch, and the sixth-order arteries were recognized as dichotomous divisions of the corresponding fifth-order arteries. Visual analysis was performed only on segments that did not show pulmonary embolism; respiratory motion artifacts; cardiac motion artifacts; pulmonary abnormalities such as consolidation, atelectasis, and edema; pleural effusion; or anatomic variants that made assignment to a vessel order impossible. Simultaneous use of a mediastinal window setting (window width, 350 H; window center, 50 H) and lung window setting (window width, 1,200 H; window center, –600 H) was applied in all investigations. For evaluation of differences in detection rates along the z-axis, the arteries of both upper lobes; the arteries of the middle lobe, the lingua, and the superior segments of the lower lobes; and the arteries of the basal segments of the lower lobes were analyzed separately.

In patients with CT confirmation of pulmonary embolism, the mean density of the emboli was computed by measuring each embolus per arterial segment three times. Subsequently, the difference in Hounsfield units between mean density of emboli and mean arterial attenuation was calculated per patient and averaged for the group. In addition, the conspicuity of the emboli was analyzed visually using a 3-point scale: low (low attenuation difference between contrast-enhanced arterial lumen and emboli), moderate (moderate attenuation difference between contrast-enhanced arterial lumen and emboli), and excellent (high-density difference between contrast-enhanced arterial lumen and emboli).

Perivenous artifacts adjacent to the superior vena cava were graded by two observers in consensus using a 3-point scale: grade 1 (negligible artifacts), grade 2 (moderate artifacts but all vessel portions clearly diagnostic), and grade 3 (severe or extensive artifacts that might lead to misinterpretation in some vessel portions).

### Statistical Analysis

Mean attenuation along the z-axis was calculated per patient, averaged for each group, and compared using Student’s t test for unpaired samples. In addition, the mean diameter of the pulmonary trunk was calculated for each group and compared using Student’s r test for unpaired samples. The significance of differences in detecting fourth-, fifth-, and sixth-order arteries and the significance of differences in classifying perivenous artifacts were tested using the chi-square test. Two-sided p values of less than 0.05 were considered to indicate statistical significance. The Statistical Package for the Social Sciences software (SPSS, Inc.) was used.

### Results

No adverse reactions occurred in our study population. The mean attenuation along the z-axis was 268 ± 56 H in group A and 344 ± 108 H in group B. The difference of 76 H was statistically significant (p < 0.001) (Fig. 1). The attenuation profile was similar in both groups, showing an increase of attenuation at an attenuation plateau and a decrease of attenuation at the end of the scanning volume (Fig. 2).

A total of 530 segments were evaluated in group A, and a total of 542 in group B. Table 2 lists the causes for exclusion of the remaining segments. In groups A and B, all subsegmental (fourth-order) arteries were depicted. In group A, 91% of the fifth-order arteries were depicted, compared with 94% in group B (p < 0.01). The detection rate of the sixth-order arteries was significantly higher in group B (72%) than in group A (60%) (p < 0.001) (Fig. 3). The arterial detection rates along the z-axis are listed in Table 3.

In the patients with CT-confirmed pulmonary embolism (11 patients in group A, 12 patients in group B) the mean density of the emboli was 59 H in group A and 51 H in group B. In these patients, the mean arterial attenuation along the z-axis was 261 H in group A and 358 H in group B. Consequently, the mean difference in Hounsfield units between emboli and contrast-enhanced arterial lumen was 202 H in group A and 307 H in group B. Emboli conspicuity was graded as low in one, moderate in seven, and excellent in three patients of group A, whereas in group B, emboli conspicuity was graded as moderate in four patients and excellent in eight patients (Fig. 3). However, statistical analysis was not performed on this subgroup because of the small number of patients.
There was no significant difference in classifying perivenous artifacts between the two groups ($p = 0.831$). In group A, perivenous artifacts were classified as minimal in 12 patients (24%), as moderate in 28 patients (56%), and as severe in 10 patients (20%). In group B, perivenous artifacts were classified as minimal in 14 patients (28%), as moderate in 25 patients (50%), and as severe in 11 patients (22%).

**Discussion**

Two aspects are crucial in the identification of small vessels in CTA: slice thickness and vessel attenuation. Several studies have revealed the influence of slice thickness and the accuracy of MDCT in the detection of subsegmental arteries in CTA of the pulmonary arteries [6, 9–12]. These studies showed that a narrow collimation significantly improved visualization of segmental and subsegmental pulmonary arteries. The visualization rate was highest with a collimation of 1.25 or 1 mm. With these detector configurations, subsegmental (fourth-order) arteries were visualized in 71–96% [9, 11], fifth-order arteries in 74% [9], and sixth-order arteries in 35% [9].

The number of iodine molecules administered over time generally determines vessel attenuation. The iodine flow concentration can be increased by increasing the injection flow rate using a contrast medium with a high iodine concentration [13]. However, increasing the injection rate implies the use of IV catheters of larger diameters, which may be impossible in some patients. In our study, a high-concentration contrast medium (400 mg I/mL) was used to assess whether...
an increased flow concentration of iodine improves attenuation and visualization of pulmonary arteries. We injected the contrast medium at an injection rate of 4 mL/sec in both groups. Therefore, 1.2 g of iodine per second was administered in group A, and 1.6 g of iodine per second in group B. The higher flow concentration of iodine in group B led to a significantly improved attenuation along the z-axis without change of the shape of the attenuation profile (Fig. 2). The result was significantly better depiction of fifth-order and sixth-order pulmonary arteries (Fig. 1). No significant difference was found in the detection rate of fourth-order arteries. The differences in detection rate of the subsegmental pulmonary arteries were similar in the upper, middle, and lower parts of the scanning volume, in accordance with the measured attenuation profile (Table 3).

The high number of visualized subsegmental and lower-order arteries in the present study, compared with the number found by prior investigations [9, 11], may be explained by the different study designs. In contrast to those investigations, we evaluated the peripheral pulmonary arteries in a well-selected subgroup of segments: All segments that showed respiratory motion artifacts; cardiac motion artifacts; pulmonary emboli; pulmonary abnormalities such as consolidation, atelectasis, and edema; pleural effusion; or anatomic variants that made assignment to a vessel order impossible were excluded from visual analysis. The purpose of this exclusion was to avoid the influence of abnormalities or artifacts on arterial visualization and thus to point out differences in visualization of subsegmental and lower order arteries due to different attenuation based on different iodine flow concentrations.

To permit statistically comparable analysis of data, we assigned patients consecutively into group A or B. The two groups showed no statistically significant difference in body weight (Table 1). Also, the incidence of pul-

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**TABLE 2** Causes for Exclusion of Segments from Visual Analysis

<table>
<thead>
<tr>
<th>Cause for Exclusion</th>
<th>Group A</th>
<th>Group B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulmonary embolism</td>
<td>133 (28)</td>
<td>120 (26)</td>
</tr>
<tr>
<td>Respiratory motion artifacts</td>
<td>136 (28)</td>
<td>140 (31)</td>
</tr>
<tr>
<td>Cardiac motion artifacts</td>
<td>24 (5)</td>
<td>32 (7)</td>
</tr>
<tr>
<td>Pulmonary abnormalities</td>
<td>48 (10)</td>
<td>41 (9)</td>
</tr>
<tr>
<td>Pleural effusion</td>
<td>91 (19)</td>
<td>75 (16)</td>
</tr>
<tr>
<td>Anatomic variants</td>
<td>47 (10)</td>
<td>50 (11)</td>
</tr>
</tbody>
</table>

Note.—Data are numbers of segments coded as not analyzable. Numbers in parentheses are percentages. In excluded segments, no analysis of subsegmental (fourth-order), fifth-order, or sixth-order arteries was performed.

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**TABLE 3** Detection Rate of Fifth- and Sixth-Order Arteries According to Position Along z-Axis

<table>
<thead>
<tr>
<th>Position of Artery</th>
<th>Group A</th>
<th>Group B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fifth Order</td>
<td>Sixth Order</td>
</tr>
<tr>
<td>Upper lobe</td>
<td>95</td>
<td>68</td>
</tr>
<tr>
<td>Middle lobe, lingula, or superior lower lobe</td>
<td>87</td>
<td>50</td>
</tr>
<tr>
<td>Lower lobe</td>
<td>88</td>
<td>55</td>
</tr>
</tbody>
</table>

Note.—Data are percentages.

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Fig. 3.—Multiplanar reformatted images of two patients with pulmonary embolism. A, 51-year-old man who underwent CT angiography (CTA) with 120 mL standard contrast media (300 mgI/mL). Axial-oblique multiplanar reformatted images through pulmonary emboli in segment artery (arrow) of left lower lobe. B, 64-year-old woman who underwent CTA with 90 mL high-concentration contrast media (400 mgI/mL). Coronal-oblique multiplanar reformatted images through pulmonary emboli in segment artery (arrow) of right lower lobe. Note better conspicuity of emboli in B. Multiplanar reformatted images were obtained for illustration only; within-study assessment of peripheral arteries was performed on axial images.
monary embolism; pleural effusion; and pulmonary abnormalities such as consolidation, atelectasis, and edema was nearly the same in both groups (Table 2). In addition, the mean diameter of the main pulmonary artery was identical in both groups. Consequently, attenuation measurements along the z-axis were unlikely to have been influenced by differences in pulmonary perfusion related to patient weight, parenchymal abnormalities, or pulmonary hypertension between the two groups. All examinations were performed with the same 4-MDCT scanner with a collimation of 1.25 mm as optimal slice thickness for detection of small pulmonary arteries [6, 9, 11, 12]. For scanners that are 16-MDCT or greater, one can assume that the volume of contrast medium may be reduced in both groups because of the shorter scanning time. The absolute attenuation values in both groups may be different from the values achieved in this investigation, because the faster data acquisition allows scanning during the plateau phase of contrast enhancement. However, the profile of the time–attenuation curve is not influenced by faster scanning; therefore, the difference in attenuation values between the two groups may not change. We used a semiautomated bolus-tracking system to consider the different cardiovascular statuses of the patients. The mean scan delay was about 15 sec in both groups. One may expect the more concentrated contrast medium to reach the threshold level more quickly than the less concentrated one. Several reasons account for the variability in start delay when using a semiautomated bolus-tracking device. First, the scans were started manually by the radiologic technicians after the threshold level had been reached on the steep upward time–attenuation curve; second, a breathing command was given after the threshold level had been reached.

A flush of saline solution was used after contrast material administration to avoid pooling of the contrast material in the arm veins and in the injection system and to reduce perivenous artifacts in the superior vena cava [16]. Doubtless, one may expect more artifacts when using more concentrated contrast media. We assume the reason for the similar artifacts in the two groups was that, in group B, injection of the contrast medium had already been completed when the scan plane reached the superior vena cava (injection time, 22.5 sec; scan delay + scanning time, 35 sec) and that the contrast medium was diluted by the saline solution flush. In group A, the injection time was 30 sec, and consequently, the contrast medium was less diluted when the scan plane reached the superior vena cava.

Emboli conspicuity was better in group B than in group A (Fig. 3). Also, the density difference between the emboli and the contrast-enhanced arterial lumen was greater in group B. However, because of the low number of patients with CT confirmation of pulmonary embolism (11 patients in group A, 12 patients in group B) we did not test statistical significance in this subgroup. In addition, analysis of conspicuity of emboli in different patient populations is spurious because there is no gold standard to prove presence or absence of emboli. One can assume that embolus conspicuity would be improved by improving pulmonary artery attenuation and visualization of small pulmonary arteries. However, further investigations are necessary to support this assumption.

The potential higher detection rate of fifth- and sixth-order arteries may be the subject of controversy, and the impact on clinical management is questionable. A higher detection rate of isolated emboli in the higher order arteries may be of clinical relevance in young patients to detect deficiency syndromes such as protein P or S resistance or lack of antithrombin III. Such detection may help to prevent further clinically relevant pulmonary embolism by allowing initiation of diagnostic and therapeutic procedures. However, further investigations are necessary for validation of this hypothesis. When it turns out that subsegmental pulmonary embolism does not affect patients’ clinical outcome, the iodine dose may be reduced without impairing attenuation of the pulmonary arteries, compared with standard contrast media.

Use of a high-concentration contrast medium may be more or less expensive than use of a standard contrast medium because of the variability in prices between vendors. The reduced volume may compensate partially or fully for the higher purchase price of the high-concentration contrast medium.

In conclusion, use of a high-concentration contrast medium significantly improves attenuation of the pulmonary arteries, leading to better visualization of subsegmental and lower-order arteries in MDCT angiography.

References

This article has been cited by:

1. Thomas Burdenski, Keno K. Bressem, Lisa C. Adams, Nils F. Grauhan, Stefan M. Niehues. 2021. CT diagnostics of pulmonary embolism: Does iodine delivery rate still affect image quality in iterative reconstruction?: Clinical Hemorheology and Microcirculation 79:1, 81-89. [Crossref]

2. Ilkay S. Idilman. CT and MR Angiography in the Chest and Abdomen 169-187. [Crossref]


6. Jae-Yeon Hwang, Ki Seok Choo, Yoon Young Choi, Jin Hyeok Kim, Hwaseong Ryu, Junhee Han, Yong-Woo Kim, Ung Ba Jeon, Kyung Jin Nam. 2017. Subjective and objective image differences in pediatric computed tomography cardiac angiography using lower iodine concentration. Pediatric Radiology 47:6, 701-709. [Crossref]

7. Kazuo Awai, Toru Higaki, Fuminari Tatsugami. Contrast Enhancement at CT 81-101. [Crossref]


10. Li Xu Cao, Huan Zhang, Bo Liu, Wen Jie Yang, Yan Yan Zhang, Zi Lai Pan, Fu Hua Yan, Ke Min Chen. 2013. Evaluation of high-pitch flash scan for pulmonary venous CTA on a 128-slice dual source CT: compared with prospective ECG-triggered sequence scan. The International Journal of Cardiovascular Imaging 29:7, 1557-1564. [Crossref]


17. Selma Uysal Ramadan, Pinar Kosar, Iclal Sonmez, Sevilay Karahan, Ugur Kosar. 2010. Optimisation of contrast medium volume and injection-related factors in CT pulmonary angiography: 64-slice CT study. European Radiology 20:9, 2100-2107. [Crossref]

37. Tamaki Ichikawa, Jun Endo, Jun Koizumi, Ayako Ro, Makiko Kobayashi, Midori Saito, Shuichi Kawada, Takeshi Hashimoto, Yutaka Imai. 2008. Visualization of the azygos arch valves on multidetector-row computed tomography. *Heart and Vessels* **23**:2, 118-123. [Crossref]

38. Zelena A. Aziz, David M. Hansell. Techniques in Thoracic Imaging 187-199. [Crossref]

39. Kyongtae T. Bae. Principles of Contrast Medium Delivery and Scan Timing in MDCT 10-24. [Crossref]


44. Morio Nagahata, Yoshinao Abe, Shuichi Ono, Hikaru Yamaguchi, Hiroyuki Miura, Takashi Ohata, Fumiyasu Tsushima, Kohei Morimoto, Hiroko Seino. 2007. Attenuation values of the intracranial arterial and venous vessels by bolus injection of various contrast agents: a study with a single-detector helical CT scanner. *Radiation Medicine* **25**:3, 89-93. [Crossref]


46. Bindu N. Setty, Dushyant V. Sahani, Kathy Ouellette-Piazza, Peter F. Hahn, Jo-Anne O. Shepard. 2006. Comparison of Enhancement, Image Quality, Cost, and Adverse Reactions Using 2 Different Contrast Medium Concentrations for Routine Chest CT on 16-Slice MDCT. *Journal of Computer Assisted Tomography* **30**:5, 818-822. [Crossref]

47. Fredrik Holmquist, Ulf Nyman. 2006. Eighty-peak kilovoltage 16-channel multidetector computed tomography and reduced contrast-medium doses tailored to body weight to diagnose pulmonary embolism in azotaemic patients. *European Radiology* **16**:5, 1165-1176. [Crossref]

48. B. Ghaye, R. F. Dondelinger. CT Diagnosis of Acute Pulmonary Embolism 347-370. [Crossref]

49. Kyongtae T. Bae. Principles of Contrast Medium Delivery and Scan Timing in MDCT 10-24. [Crossref]

50. Martin H.K. Hoffmann. Contrast Agent Application and Protocols 97-108. [Crossref]