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EMERGENCY RADIOLOGY SPECIAL FEATURE: FULL PAPER

Individually tailored contrast enhancement in CT pulmonary angiography

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Objective: The purpose was to evaluate individually shaped contrast media (CM) delivery in CT pulmonary angiography (CTPA) for suspected pulmonary embolism (PE).

Methods: 100 consecutive emergency patients with clinical suspicion of PE were evaluated. High-pitch CTPA was performed on a second-generation dual-source CT using the following parameters: 100 kV, 200–250 mAsref, rotation time 0.28 s, 128 × 0.6 mm col. and image reconstruction 1.0/0.8 mm (B30f). Group 1 ($n = 50$) then received a fixed CM bolus ($300 = \text{mgI ml}^{-1}$, volume = 90 ml and flow rate = 6 ml s^{-1}); Group 2 ($n = 50$) received a body weight-adapted CM bolus determined by dedicated contrast injection software. For analysis, groups were further subdivided into low-weight (40–75 kg) and high-weight (76–117 kg) groups. Technical image quality was graded using a four-point Likert scale (1 = non-diagnostic; 2 = diagnostic; 3 = good and 4 = excellent image quality) at the level of the pulmonary trunk and pulmonary arteries. Objective image quality analysis was performed by measuring contrast enhancement in Hounsfield units

(HU) at the same levels. Attenuation levels > 180 HU were considered diagnostic.

Results: All examinations were graded as diagnostic at each level. The individual minimum pulmonary attenuation was 184 and 270 HU for Group 1 and 2, respectively. Mean attenuation was as follows: Group 1: 475 ± 105 HU (40–75 kg) and 402 ± 115 HU (76–117 kg), $p < 0.03$. Group 2: 424 ± 76 HU (40–75 kg) and 418 ± 100 HU (76–117 kg), $p = 0.8$. For Group 2, CM volumes were: 55 ± 5 ml (40–75 kg) and 66 ± 5 ml (76–117 kg), leading to 16–51% CM reduction.

Conclusion: Even under emergency conditions, individualized CM protocols can provide diagnostic and robust image quality in CTPA for PE with a substantial reduction of CM volume for lower weight patients, compared with a fixed CM protocol.

Advances in knowledge: CM volume can substantially be reduced by using individualized CM protocols in CT angiography for PE without compromising the diagnostic image quality.

INTRODUCTION

Pulmonary embolism (PE) is a major cause of morbidity and mortality, with acute PE being the most severe clinical presentation.¹ CT pulmonary angiography (CTPA) is widely used to rule out or confirm the presence of PE and is considered the reference standard for this emergency indication.^{2,3} The improvement of scanning techniques with the invention of the multidetector-row CT has led to a high spatial and temporal resolution, better delineation of peripheral arteries and increased detection rate of sub-segmental PE.^{3,4} In addition, CTPA has been shown to provide an alternative diagnosis in up to 70% of patients in whom PE is not confirmed.⁵ The diagnostic and clinical value of CTPA has already been firmly substantiated;^{5–8}

thus, future research should focus on optimizing scan protocols and improving workflow.^{9,10}

A considerable obstacle in current clinical practice is a substantial number of non-diagnostic scans, with reported rates ranging between 3.3% and 7.3%.^{11,12} However, for an emergency indication such as PE, the scan protocol should be expected to deliver robust and reliable results 24 h a day, 7 days a week. According to current literature, a diagnostically enhanced CTPA requires an intra-arterial attenuation of at least 180 Hounsfield units (HU), which allows for the visualization of pulmonary pathology in at least 90% of the patient population.^{11,13} The enhancement of pulmonary arteries depends on multiple factors:

scan technique including tube settings (kV; mAs), scan duration, patient-related factors such as breathing (Valsalva) and body weight as well as contrast media (CM) administration parameters.^{11,14,15} Regarding the latter, both the amount of iodine injected per second [iodine delivery rate (IDR)] and the total amount of iodine [total iodine load (TIL)] are important factors in the enhancement of pulmonary arteries.^{5,14–16} One of the most influential patient-related factors is body weight; arterial enhancement and body weight have been found to correlate significantly, as well as enhancement and body mass index.^{14,15} Therefore, fixed CM protocols may result in attenuation values below the diagnostic level for heavier patients, whereas for skinny patients, attenuation may exceed required levels. Therefore, a solution could possibly be found in individualizing contrast application for each patient. This study aimed to prospectively evaluate individually shaped CM delivery in emergency CTPA for suspected PE.

METHODS AND MATERIALS

Ethics

A waiver of written informed consent was obtained from the local ethical committee (METC, ref. 14-4-198).

Study population

Inclusion criteria were: referral for CTPA for suspected PE; ≥ 18 years of age; and a glomerular filtration rate $\geq 60 \text{ ml min}^{-1} \times 1.73 \text{ m}^2$. All patients were weighed by radiological technicians directly before CTPA; in case of immobile patients, weighing was sometimes obstructed, and the last known weight was recorded from the electronic patient files, when available. Patients were excluded when an alternative scan protocol (e.g. higher kilovoltage; kV) had to be used ($n = 11$) or when body weight/injection data were incomplete ($n = 25$). A total of 100 consecutive patients were included for data analysis.

Imaging protocol

All scans were performed on a second-generation dual-source multidetector-row CT scanner (Somatom® Definition Flash; Siemens Healthcare, Forchheim, Germany) using a high-pitch CT angiography (CTA) protocol ("Flash") with a tube voltage of 100 kV, tube current of 200–250 mAs_{ref} (CareDose 4D™; Siemens) and pitch value of 2.6. A gantry rotation time of 0.28 s and slice collimation of $128 \times 0.6 \text{ mm}$ were applied. Image

reconstruction was performed using a medium soft-tissue kernel (Siemens B30f) at a slice thickness of 1 mm with an overlapping increment of 0.8 mm.

Contrast media injection protocol

Pre-warmed [37°C (99°F)] CM (Ultravist®, Iopromide 300 mgI ml⁻¹; Bayer Healthcare, Berlin, Germany) was used for all patients. CM was administered using a programmable dual-head CT injector (Stellant®; Bayer) via an 18–20 G intravenous injection catheter in the left or right antecubital vein.

The first 50 patients (Group 1) received CM injection according to our clinical standard PE protocol consisting of a CM phase of 75 ml, as well as a mixed phase with total 30 ml of 50% CM and 50% NaCl (TIL: 27 gI). Flow rate was 6.0 ml s^{-1} (IDR: 1.8 gI s^{-1}). All CM injections were followed by a saline chaser of 30 ml at the same flow rate.

The second 50 patients (Group 2) received individual CM injection protocols adjusted to body weight (kg) and scan duration (s), calculated by a dedicated contrast injection software (Certegra™ P3T; Bayer). This injection software is able to calculate CM volume and flow rate based on a non-linear relationship between patient weight and duration of the CT data acquisition.^{17,18} After the body weight of the patient and average scan duration for the specific acquisition are provided by the user, CM volume and flow rate will be adapted simultaneously in order to provide similar injection duration for each patient. All injections were followed by a saline chaser of 30 ml at the same calculated flow rates.

For both groups, individual bolus timing in order to generate an individual start delay was performed using test bolus technique at the level of the pulmonary trunk: 20 ml of CM was followed by 40 ml of saline using the flow rates pre-calculated for the diagnostic scan. An overview of all injection parameters is listed in Table 1.

Clinical outcome

All images were immediately clinically evaluated by experienced radiologists. Information about the presence and location of PE was collected from the clinical reports.

Table 1. Injection protocols as used in this study

Injection parameters	CM bolus (ml)	Mixed phase ^a (ml)	Saline chaser (ml)	Flow rate (ml s ⁻¹)	TIL (gI)	IDR (gI s ⁻¹)
Group 1	75	30 (CM: 15 NaCl: 15)	30	6.0	27	1.8
Group 2						
40–75 kg	42–60	–	30	4.2–6.0	13–18	1.3–1.8
76–117 kg	61–76	–	30	6.1–7.6	18–23	1.8–2.3

CM, contrast media; IDR, iodine delivery rate; TIL, total iodine load.

^aThe mixed phase consisted of 50% CM and 50% NaCl.

For Group 1, the injection protocol was fixed for all patients ($n = 50$). In Group 2, the injection protocol was adapted according to the patient weight in kilograms; this table shows the ranges of parameters that were used.

Figure 1. Images show the regions of interest for attenuation measurement at the level of the pulmonary trunk (top left), right pulmonary artery (right top), left pulmonary artery (left bottom) and paraspinal muscle (right bottom).

Data processing

Acquired data were analysed on a dedicated medical workstation (SyngoVia™; Siemens) using 1-mm transverse sections. Technical image quality of all scans was graded by an experienced research fellow (MK) who was blinded to the injection protocols, using a four-point Likert scale (1 = non-diagnostic; 2 = diagnostic; 3 = good; and 4 = excellent image quality) at the level of the left pulmonary artery (LPA) and right pulmonary artery (RPA) as well as at the level of lobular, segmental and subsegmental arteries. Technical image quality was determined as a combination of contrast enhancement, image noise and the presence of artefacts.

Objective image quality including contrast enhancement in HU, contrast-to-noise ratio (CNR) and signal-to-noise ratio (SNR) was measured by a research fellow (BH) who was blinded to the injection protocols. Regions of interest were

manually delineated on the axial thin slices at the level of the origin of the pulmonary trunk (PT) just cranial to the pulmonary valve and in both LPA and RPA (Figure 1). Sufficient image quality was defined as attenuation values >180 HU and CNR values ≥ 10 .¹⁹ SNR and CNR were defined according to the following equations:¹³

$$\text{SNR} = \frac{\text{mean pulmonary enhancement (HU)}}{\text{mean pulmonary enhancement standard deviation (HU)}}$$

$$\text{CNR} = \frac{\text{mean pulmonary enhancement (HU)} - \text{paraspinal muscle enhancement (HU)}}{\text{paraspinal muscle enhancement standard deviation (HU)}}$$

All injection parameters (volume, flow rate, peak flow rate and peak pressure) were continuously monitored by a data acquisition program (Certegra™ Informatics Platform; Bayer) and read out after each injection.

Table 2. Baseline characteristics

Patient characteristics	Age (years)	Sex (% male)	Body weight (kg)	Height (cm)	BMI (kg m^{-2})
Group 1	64 $\pm$ 15	54	75 $\pm$ 17	169 $\pm$ 9	26 $\pm$ 5
Group 2	63 $\pm$ 16	46	71 $\pm$ 15	170 $\pm$ 8	25 $\pm$ 5
<i>p</i> -value	0.79	0.42	0.26	0.82	0.25

BMI, body mass index.

This table shows baseline characteristics of the two main groups; no significant differences were found.

Table 3. Injection parameters for both groups

Injection parameters		Flow rate (ml s ⁻¹)	Peak flow rate (ml s ⁻¹)	IDR (gI s ⁻¹)	Main bolus volume (ml)	TIL (g)	Iodine per kg (g)	Peak pressure (psi)
Group 1	Low weight (40–75 kg)	5.8 ± 0.3	6.3 ± 0.0	1.8 ± 0.0	89.5 ± 1.1	26.8 ± 0.3	0.43 ± 0.05	103 ± 18
	High weight (76–117 kg)	5.7 ± 0.1	6.3 ± 0.0	1.8 ± 0.0	90.0 ± 0.3	26.9 ± 0.1	0.30 ± 0.03	106 ± 26
Group 2	Low weight (40–75 kg)	5.2 ± 0.4	5.8 ± 0.5	1.6 ± 0.1	54.6 ± 4.5	16.4 ± 1.4	0.26 ± 0.05	99 ± 17
	High weight (76–117 kg)	6.1 ± 0.4	7.0 ± 0.5	2.0 ± 0.1	65.6 ± 4.7	19.7 ± 1.4	0.20 ± 0.00	122 ± 33
<i>p</i> -value		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.33

IDR, iodine delivery rate; TIL, total iodine load.

A significant decrease is seen for TIL, main bolus volume and iodine per kg for the individualized protocol vs standard protocol, in both low- and high-weight groups.

Statistical analysis

Statistical analysis was performed using SPSS v. 22.0 (IBM Corp., New York, NY; formerly SPSS Inc., Chicago, IL). For comparison between different body weights, patients were divided into two groups: 40–75 kg (low weight) and 76–117 kg (high weight). Groups were checked for normal distribution using the Kolmogorov–Smirnov test. Continuous variables were reported as the mean ± standard deviation, and differences between groups were calculated using one-way analysis of variance with a Tukey test for *post hoc* comparisons. Categorical variables were reported as percentages, and the χ^2 test was used to measure differences between groups. All *p*-values are two-sided, and a *p*-value below 0.05 was considered statistically significant.

Figure 2. Scatter dot shows all patients by weight in kilograms with their corresponding received contrast media (CM) volume. All Group 1 patients received 90 ml CM. All patients in Group 2 received less CM (range: 44–76 ml), and for low-weight patients, the CM dose reduction was most pronounced.

RESULTS

Baseline characteristics

Baseline characteristics of the study population are summarized in Table 2; no significant differences in baseline characteristics were found. For Group 1, mean age (years), body weight (kg) and body mass index (kg m⁻²) were 64 ± 15 (range: 16–91), 75 ± 17 (range: 49–109) and 26 ± 5 (range: 18–39). For Group 2, these values were 63 ± 16 (range: 21–92), 71 ± 15 (range: 43–117) and 25 ± 5 (range: 15–39), with associated *p*-values of 0.79, 0.26 and 0.25, respectively.

Figure 3. This bar graph shows the mean iodine per kilogram load for the low-weight and high-weight patients in Group 1 (left) and Group 2 (right). The iodine per kilogram is reduced for Group 2 both in low- and high-weight categories.

Table 4. Extension of pulmonary embolism in each group

Group	Standard										Individualized							
Central			X	X	X													
Lobar		X	X	X	X		X							O				O
Segmental	X	X	X	X		X	X	X	X	X	O			O	O	O	O	O
Subsegmental		X	X	X		X	X	X				O	O	O	O	O	O	O

Each column represents one patient and the extent of disease found. 18 patients showed pulmonary embolism, with $n = 10$ in Group 1 and $n = 8$ in Group 2.

Injection parameters

Mean flow rates in Group 2 were $5.2 \pm 0.4 \text{ ml s}^{-1}$ for patients between 40–75 kg and $6.1 \pm 0.4 \text{ ml s}^{-1}$ for patients between 76–117 kg, ranging from 4.2 to 7.6 ml s^{-1} . CM volumes were calculated as between 42 ml (40 kg) and 76 ml (117 kg); IDR ranged from 1.26 to 2.28 g l s^{-1} and TIL from 12.6 to 22.8 g, respectively. Peak pressures for both groups ranged between $99 \pm 17 \text{ psi}$ and $122 \pm 33 \text{ psi}$ and did not differ significantly between Groups 1 and 2, with $p > 0.3$ (Table 3). Maximal injection pressure of 325 psi was never reached in any patient or for any flow rate.

TIL was 27 g for Group 1 and ranged from 12.6 to 22.8 g in Group 2. The mean TIL for Group 2 was $16 \pm 1.4 \text{ g}$ (40–75 kg) and $20 \pm 1.4 \text{ g}$ (76–117 kg), showing a significant CM dose reduction for all patients compared with Group 1, with $p < 0.01$ (Table 3 and Figure 2). In patients who received an individualized bolus, CM volume could be reduced by 51%, 33% and 16% for the lightest patient of (44 ml at 42 kg), an average patient (60 ml at 75 kg) and the heaviest patient of Group 2 (76 ml at 117 kg), respectively.

For both weight groups, the iodine per kilogram body weight was significantly lower in Group 2, with $p < 0.01$. Iodine per kilogram body weight in Group 1 was: 0.4 g l kg^{-1} for 40–75 kg and 0.3 g l kg^{-1} for 76–117 kg patients. For the same weight groups, values in Group 2 were 0.3 and 0.2 g l kg^{-1} , respectively (Table 3 and Figure 3).

Clinical outcome

The total incidence of PE in this study population was 18%. In Group 1, a total of 10 patients were diagnosed with PE, including 2

central, 3 lobar and 5 segmental emboli. Group 2 showed eight patients with PE; two patients had lobar PE, three patients had segmental PE and three had subsegmental PE. These are the most proximal points of the emboli; for an overview of the extent of disease in each patient, see Table 4.

Technical image quality

For both groups, all scans were graded as diagnostic image quality at each anatomic level. The lowest grade was 2, and this grade was found in only one patient of each group. All other scans were graded as “good” or “excellent” at each anatomic level.

Objective image quality

For Group 1, mean attenuation values in the PT and in the RPA and LPA were as follows (40–75 kg vs 76–117 kg): 475 ± 105 vs $402 \pm 115 \text{ HU}$ (PT), 435 ± 94 vs $369 \pm 104 \text{ HU}$ (RPA) and 426 ± 101 vs $360 \pm 102 \text{ HU}$ (LPA). There was a significant difference in attenuation values between weight groups for PT, LPA and RPA, with all p -values < 0.03 (Table 5). For Group 2, these attenuation values were as follows (40–75 vs 76–117 kg): 424 ± 76 vs $418 \pm 100 \text{ HU}$ (PT), 418 ± 84 vs $408 \pm 90 \text{ HU}$ (RPA) and 413 ± 81 vs $403 \pm 92 \text{ HU}$ (LPA). Within Group 2, no significant differences were found in attenuation values between both weight groups; all p -values > 0.6 (Table 5).

On a group level, no significant differences in attenuation values were found between Group 1 and 2. However, attenuation values for Group 2 show a much smaller range (Figures 4 and 5). Both groups showed no non-diagnostic scans with a minimum mean pulmonary attenuation of 184 HU for Group 1 and 270 HU for Group 2.

Table 5. Mean pulmonary artery attenuation values

Objective image quality		PT (HU $\pm$ SD)	RPA (HU $\pm$ SD)	LPA (HU $\pm$ SD)	CNR	SNR
Group 1	Low weight 40–75 kg	475 ± 105	435 ± 94	426 ± 101	15 ± 5	14 ± 4
	High weight 76–117 kg	402 ± 115	369 ± 104	360 ± 102	11 ± 5	11 ± 3
p -value		0.03	0.03	0.03	> 0.01	> 0.01
Group 2	Low weight 40–75 kg	424 ± 76	418 ± 84	413 ± 81	16 ± 6	15 ± 5
	High weight 76–117 kg	418 ± 100	408 ± 90	403 ± 92	15 ± 5	13 ± 3
p -value		0.80	0.67	0.70	0.24	> 0.01

CNR, contrast-to-noise ratio; HU, Hounsfield units; LPA, left pulmonary artery; PT, pulmonary trunk; RPA, right pulmonary artery; SD, standard deviation; SNR, signal-to-noise ratio.

Mean attenuation values for low- and high-weight groups per injection protocol and per artery, comparing a low-weight and high-weight group.

Figure 4. Error bars show the mean attenuation and 95% confidence intervals for both injection protocols and weight groups. The intervals define the values that are most plausible for the mean of a greater population. A decreased mean attenuation was seen for the higher weight group within the standard protocol (left) and similar mean attenuation was seen for both weight groups within the individualized protocol (right). HU, Hounsfield units.

CNR was acceptable for both groups, but better for Group 2, with values (low weight–high weight) of 16 ± 6 and 15 ± 5 vs 15 ± 5 and 11 ± 5 . SNR values for Group 1 were 14 ± 4 (low

weight) and 11 ± 3 (high weight); for Group 2, these values were 15 ± 5 and 13 ± 3 , respectively (Table 5).

DISCUSSION

Individualized CM bolus administration in CTPA provided equal-to-superior enhancement compared with a fixed protocol whilst using less CM volume. Moreover, greater consistency of vascular enhancement values—indicating a more reliable and robust protocol—was observed throughout Group 2, whereas the scans for Group 1 showed a steady decline in attenuation with increasing body weight. The observed homogeneity of attenuation throughout all patient weights is concordant with other studies using CM individualization in CTA; however, this research shows an additional reduction of CM volume as well.^{17,20}

Some studies on body weight-adapted CM protocols for CTPA in selective, low-weight patient groups have been published: Holmquist *et al* used an 80-kV protocol with TIL of around 13 g in a low-weight patient group, and Kristiansson *et al* reduced the TIL in a similar patient group even further to 9.6 g. However, 8–12% of the examinations were regarded as suboptimal.^{21,22} In coronary CTA, a smaller standard deviation of intracoronary attenuation was reported when using a body weight-adapted injection protocol, indicating a smaller variation in attenuation values between individual patients.^{17,20}

In CTPA, the lower HU limit is important as CM attenuation is typically even lower in the more peripheral arteries. A CTPA with arterial attenuation below 180 HU may be considered to be

Figure 5. Images show contrast enhancement at the level of the pulmonary trunk (W–C levels: 600–125). Left images show two patients from Group 1 including low weight (top) and high weight (bottom) with attenuation values of 532 and 362 HU, respectively. Right images show two patients from Group 2 including low weight (top) and high weight (bottom) with attenuation values of 555 and 520 HU, respectively. Both bottom images also show right lobar pulmonary embolism.

of non-diagnostic quality to reliably detect subsegmental emboli as mean HU values for acute and chronic embolism are around 33 and 87 HU, respectively.²³ In this study, all patients met this crucial cut-off value of 180 HU.

CNR was sufficient in both groups. CNR values above 10 are generally accepted in coronary CTA literature;¹⁹ however, there is currently no consensus regarding CNR values in CTPA. In this study, CNR decreased significantly with increasing patient weight in Group 1, whereas CNR remained constant in the group with individualized CM injections (Group 2). The observed decrease in CNR can be attributed to lower CM attenuation values in heavier patients in combination with higher image noise owing to higher body mass.^{19,24} A further improvement in CNR could be achieved by alteration of reconstruction methods, for example, with the implementation of iterative reconstruction.^{25–27} However, subjective image quality will not always be experienced as superior owing to possible loss of contrast between different densities.

All patients (up to 117 kg) from the individualized CM group received less CM compared with standard group patients. The original fixed protocol in this study used a broad CM bolus (injection over 20 s) with a relatively high flow rate (IDR of 1.8 gI s^{-1}), which had been chosen as a safe option. Problems regarding the realization of diagnostic quality in CTPA previously called for a safe “one size fits all” bolus, in order to prevent double scanning and bolus administration. Consequently, part of the CM reduction in the individualized group can be traced back to the comparison with a generous fixed CM bolus. Nevertheless, even attenuation in patients weighing 76–117 kg from the individualized group was higher than that of patients of equal body weight in the standard group. The use of relatively smaller CM volumes in combination with higher flow rates indicates an inferior importance of CM volume and TIL compared with flow rate and IDR with respect to arterial enhancement, even under emergency conditions: IDR can be manipulated by adjusting either flow rate or iodine concentration of CM [$\text{IDR} (\text{gI s}^{-1}) = \text{flow rate} (\text{ml s}^{-1}) \times \text{iodine concentration} (\text{gI ml}^{-1})$]. Some authors state that attenuation in CTA could be increased by using higher iodine concentrations of CM,²⁸ whereas others state that increasing IDR—by increasing flow rate—is the most influencing factor regarding CM enhancement.^{16,29} Increasing

flow rate might be preferable for optimizing CM application for CTA, since increasing iodine concentration of CM simultaneously increases CM viscosity. A phantom study conducted by Kok et al³⁰ showed that low concentration, low viscosity and pre-warmed CM are beneficial for achieving low injection pressures.

Nowadays, contrast-induced nephropathy might not be as much of a concern as previously suspected.^{31,32} However, Lee et al³³ found thyroid dysfunction in 22% of patients after a single iodinated CM injection, with urinary iodine excretion correlating to the TIL. According to a recent review, contrast-induced thyroid dysfunction mostly appears to be transient; however, there is a risk of complications.³⁴ The precise relationship between CM volume and thyroid dysfunction remains unclear to this point; thus, administering smaller volumes of CM might prove to be a safe option and help to avoid delays in scheduling CTPA. Furthermore, smaller bolus volumes in other CTA protocols have been shown to reduce costs in medical clinics.³⁵

With the current scan protocol, a tube voltage of 100 kV was used. Already some advancements have been made using lower kV settings in CTA.^{25–27,36–38} A decrease in kV increases intra-arterial CM attenuation, because the higher photon energy at lower kV settings is closer to the iodine k-edge of keV.^{4,24,39,40} Many studies focused on low kV protocols; however, one must ensure to concordantly increase mAs to avoid excessive image noise.^{19,41,42} For future optimization, it may prove beneficial to further define the optimal IDR values and CM volumes per weight category that ensure a mean attenuation of 180–300 HU for all kV settings regularly used in clinics, e.g. 120, 100 and 80 kV.

Limitations

For this study, only a dedicated scan protocol at 100 kV was used. This resulted in exclusion of patients with body weights requiring higher kV protocols, e.g. 150 kg body weight at 120 kV.

CONCLUSION

The use of individualized CM protocols provides diagnostic and robust enhancement in emergency CTPA, as well as a substantial CM volume reduction in lower weight patients, compared with a fixed CM protocol.

REFERENCES

- Cohen AT, Agnelli G, Anderson FA, Arcelus JJ, Bergqvist D, Brecht JG, et al. Venous thromboembolism (VTE) in Europe. The number of VTE events and associated morbidity and mortality. *Thromb Haemost* 2007; **98**: 756–64.
- Remy-Jardin M, Pistolesi M, Goodman LR, Gefter WB, Gottschalk A, Mayo JR, et al. Management of suspected acute pulmonary embolism in the era of CT angiography: a statement from the Fleischner Society. *Radiology* 2007; **245**: 315–29. doi: [10.1148/radiol.2452070397](https://doi.org/10.1148/radiol.2452070397)
- Konstantinides SV. 2014 ESC Guidelines on the diagnosis and management of acute pulmonary embolism. *Eur Heart J* 2014; **35**: 3145–6. doi: [10.1093/eurheartj/ehu393](https://doi.org/10.1093/eurheartj/ehu393)
- Bae KT. Intravenous contrast medium administration and scan timing at CT: considerations and approaches. *Radiology* 2010; **256**: 32–61. doi: [10.1148/radiol.10090908](https://doi.org/10.1148/radiol.10090908)
- MacDonald SL, Mayo JR, eds. Computed tomography of acute pulmonary embolism. *Semin Ultrasound CT MR* 2003; **24**: 217–31.
- Moore LK, Jackson WL Jr, Shorr AF, Jackson JL. Meta-analysis: outcomes in patients with suspected pulmonary embolism managed with computed tomographic pulmonary angiography. *Ann Intern Med* 2004; **141**: 866–74. doi: [10.7326/0003-4819-141-11-200412070-00011](https://doi.org/10.7326/0003-4819-141-11-200412070-00011)

7. Mos IC, Klok FA, Kroft LJ, DE Roos A, Dekkers OM, Huisman MV. Safety of ruling out acute pulmonary embolism by normal computed tomography pulmonary angiography in patients with an indication for computed tomography: systematic review and meta-analysis. *J Thromb Haemost* 2009; **7**: 1491–8.
8. Quiroz R, Kucher N, Zou KH, Kipfmüller F, Costello P, Goldhaber SZ, et al. Clinical validity of a negative computed tomography scan in patients with suspected pulmonary embolism: a systematic review. *JAMA* 2005; **293**: 2012–17. doi: [10.1001/jama.293.16.2012](https://doi.org/10.1001/jama.293.16.2012)
9. Cronin P, Weg JG, Kazerooni EA. The role of multidetector computed tomography angiography for the diagnosis of pulmonary embolism. *Semin Nucl Med* 2008; **38**: 418–31. doi: [10.1053/j.semnucmed.2008.07.002](https://doi.org/10.1053/j.semnucmed.2008.07.002)
10. Schoepf UJ. Pulmonary artery CTA. *Tech Vasc Interv Radiol* 2006; **9**: 180–91. doi: [10.1053/j.tvir.2007.03.004](https://doi.org/10.1053/j.tvir.2007.03.004)
11. Ozawa Y, Hara M, Shibamoto Y. The frequency of insufficient contrast enhancement of the pulmonary artery in routine contrast-enhanced chest CT and its improvement with an increased injection rate: a prospective study. *J Thoracic Imaging* 2011; **26**: 42–7. doi: [10.1097/RTI.0b013e3181ced07a](https://doi.org/10.1097/RTI.0b013e3181ced07a)
12. He J, Wang F, Dai HJ, Li M, Wang Q, Yao Z, et al. Chinese multi-center study of lung scintigraphy and CT pulmonary angiography for the diagnosis of pulmonary embolism. *Int J Cardiovasc Imaging* 2012; **28**: 1799–805. doi: [10.1007/s10554-012-0013-9](https://doi.org/10.1007/s10554-012-0013-9)
13. Delesalle MA, Pontana F, Duhamel A, Faivre JB, Flohr T, Tacelli N, et al. Spectral optimization of chest CT angiography with reduced iodine load: experience in 80 patients evaluated with dual-source, dual-energy CT. *Radiology* 2013; **267**: 256–66. doi: [10.1148/radiol.12120195](https://doi.org/10.1148/radiol.12120195)
14. Bae KT, Tao C, Gurel S, Hong C, Zhu F, Gebke TA, et al. Effect of patient weight and scanning duration on contrast enhancement during pulmonary multidetector CT angiography. *Radiology* 2007; **242**: 582–9. doi: [10.1148/radiol.2422052132](https://doi.org/10.1148/radiol.2422052132)
15. Schoellnast H, Deutschmann HA, Berghold A, Fritz GA, Schaffler GJ, Tillich M. MDCT angiography of the pulmonary arteries: influence of body weight, body mass index, and scan length on arterial enhancement at different iodine flow rates. *AJR Am J Roentgenol* 2006; **187**: 1074–8. doi: [10.2214/AJR.05.0714](https://doi.org/10.2214/AJR.05.0714)
16. Muhl C, Wildberger JE, Jurencak T, Yanniello MJ, Nijssen EC, Kalafut JF, et al. Intravascular enhancement with identical iodine delivery rate using different iodine contrast media in a circulation phantom. *Invest Radiol* 2013; **48**: 813–18. doi: [10.1097/RLI.0b013e31829979e8](https://doi.org/10.1097/RLI.0b013e31829979e8)
17. Seifarth H, Puesken M, Kalafut JF, Wienbeck S, Wessling J, Maintz D, et al. Introduction of an individually optimized protocol for the injection of contrast medium for coronary CT angiography. *Eur Radiol* 2009; **19**: 2373–82. doi: [10.1007/s00330-009-1421-7](https://doi.org/10.1007/s00330-009-1421-7)
18. Bae KT, Heiken JB, Brink JA. Aortic and hepatic contrast medium enhancement at CT. Part II. Effect of reduced cardiac output in a porcine model. *Radiology* 1998; **207**: 657–62. doi: [10.1148/radiology.207.3.9609887](https://doi.org/10.1148/radiology.207.3.9609887)
19. Lee SM, Lee W, Chung JW, Park EA, Park JH. Effect of kVp on image quality and accuracy in coronary CT angiography according to patient body size: a phantom study. *Int J Cardiovasc Imaging* 2013; **29**(Suppl. 2): 83–91.
20. Nakaura T, Awai K, Yauaga Y, Nakayama Y, Oda S, Hatemura M, et al. Contrast injection protocols for coronary computed tomography angiography using a 64-detector scanner: comparison between patient weight-adjusted- and fixed iodine-dose protocols. *Invest Radiol* 2008; **43**: 512–19. doi: [10.1097/RLI.0b013e3181727505](https://doi.org/10.1097/RLI.0b013e3181727505)
21. Holmquist F, Hansson K, Pasquariello F, Björk J, Nyman U. Minimizing contrast medium doses to diagnose pulmonary embolism with 80-kVp multidetector computed tomography in azotemic patients. *Acta Radiologica* 2009; **50**: 181–93. doi: [10.1080/02841850802657269](https://doi.org/10.1080/02841850802657269)
22. Kristiansson M, Holmquist F, Nyman U. Ultralow contrast medium doses at CT to diagnose pulmonary embolism in patients with moderate to severe renal impairment: a feasibility study. *Eur Radiol* 2010; **20**: 1321–30. doi: [10.1007/s00330-009-1691-0](https://doi.org/10.1007/s00330-009-1691-0)
23. Wittram C, Maher MM, Halpern EF, Shepard JA. Attenuation of acute and chronic pulmonary emboli. *Radiology* 2005; **235**: 1050–4. doi: [10.1148/radiol.2353040387](https://doi.org/10.1148/radiol.2353040387)
24. Nakayama Y, Awai K, Funama Y, Hatemura M, Imuta M, Nakaura T, et al. Abdominal CT with low tube voltage: preliminary observations about radiation dose, contrast enhancement, image quality, and noise. *Radiology* 2005; **237**: 945–51. doi: [10.1148/radiol.2373041655](https://doi.org/10.1148/radiol.2373041655)
25. Laqmani A, Regier M, Veldhoen S, Backhaus A, Wassenberg F, Sehner S, et al. Improved image quality and low radiation dose with hybrid iterative reconstruction with 80kV CT pulmonary angiography. *Eur J Radiol* 2014; **83**: 1962–9. doi: [10.1016/j.ejrad.2014.06.016](https://doi.org/10.1016/j.ejrad.2014.06.016)
26. Lu GM, Luo S, Meinel FG, McQuiston AD, Zhou CS, Kong X, et al. High-pitch computed tomography pulmonary angiography with iterative reconstruction at 80 kVp and 20 mL contrast agent volume. *Eur Radiology* 2014; **24**: 3260–8. doi: [10.1007/s00330-014-3365-9](https://doi.org/10.1007/s00330-014-3365-9)
27. Oda S, Utsunomiya D, Yuki H, Kai N, Hatemura M, Funama Y, et al. Low contrast and radiation dose coronary CT angiography using a 320-row system and a refined contrast injection and timing method. *J Cardiovasc Comput Tomogr* 2015; **9**: 19–27. doi: [10.1016/j.jcct.2014.12.002](https://doi.org/10.1016/j.jcct.2014.12.002)
28. Ramgren B, Björkman-Burtscher IM, Holtas S, Siemund R. CT angiography of intracranial arterial vessels: impact of tube voltage and contrast media concentration on image quality. *Acta Radiol* 2012; **53**: 929–34. doi: [10.1258/ar.2012.120218](https://doi.org/10.1258/ar.2012.120218)
29. Hansmann J, Fink C, Jost G, Pietsch H, Meyer M, Nance JW Jr, et al. Impact of iodine delivery rate with varying flow rates on image quality in dual-energy CT of patients with suspected pulmonary embolism. *Acad Radiol* 2013; **20**: 962–71. doi: [10.1016/j.acra.2013.02.013](https://doi.org/10.1016/j.acra.2013.02.013)
30. Kok M, Muhl C, Mingels AA, Kietselaer BL, Muhlenbruch G, Seehofnerova A, et al. Influence of contrast media viscosity and temperature on injection pressure in computed tomographic angiography: a phantom study. *Invest Radiol* 2014; **49**: 217–23. doi: [10.1097/RLI.0000000000000019](https://doi.org/10.1097/RLI.0000000000000019)
31. Langner S, Stumpe S, Kirsch M, Petrik M, Hosten N. No increased risk for contrast-induced nephropathy after multiple CT perfusion studies of the brain with a non-ionic, dimeric, iso-osmolal contrast medium. *AJNR Am J Neuroradiol* 2008; **29**: 1525–9. doi: [10.3174/ajnr.A1164](https://doi.org/10.3174/ajnr.A1164)
32. McDonald RJ, McDonald JS, Bida JP, Carter RE, Fleming CJ, Misra S, et al. Intravenous contrast material-induced nephropathy: causal or coincident phenomenon? *Radiology* 2013; **267**: 106–18. doi: [10.1148/radiol.12121823](https://doi.org/10.1148/radiol.12121823)
33. Lee SY, Chang DL, He X, Pearce EN, Braverman LE, Leung AM. Urinary iodine excretion and serum thyroid function in adults after iodinated contrast administration. *Thyroid* 2015; **25**: 471–7. doi: [10.1089/thy.2015.0024](https://doi.org/10.1089/thy.2015.0024)
34. Lee SY, Rhee CM, Leung AM, Braverman LE, Brent GA, Pearce EN. A review: Radiographic iodinated contrast media-induced thyroid dysfunction. *J Clin Endocrinol Metab* 2015; **100**: 376–83. doi: [10.1210/jc.2014-3292](https://doi.org/10.1210/jc.2014-3292)
35. Arana E, Marti-Bonmati L, Tobarra E, Sierra C. Cost reduction in abdominal CT by weight-adjusted dose. *Eur J Radiol* 2009; **70**: 507–11. doi: [10.1016/j.ejrad.2008.01.048](https://doi.org/10.1016/j.ejrad.2008.01.048)

36. Kalender WA, Deak P, Kellermeier M, van Straten M, Vollmar SV. Application-and patient size-dependent optimization of x-ray spectra for CT. *Med Phys* 2009; **36**: 993–1007. doi: [10.1118/1.3075901](https://doi.org/10.1118/1.3075901)
37. Meinel FG, Canstein C, Schoepf UJ, Sedlmaier M, Schmidt B, Harris BS, et al. Image quality and radiation dose of low tube voltage 3rd generation dual-source coronary CT angiography in obese patients: a phantom study. *Eur Radiol* 2014; **24**: 1643–50. doi: [10.1007/s00330-014-3194-x](https://doi.org/10.1007/s00330-014-3194-x)
38. Schueller-Weidekamm C, Schaefer-Prokop CM, Weber M, Herold CJ, Prokop M. CT angiography of pulmonary arteries to detect pulmonary embolism: improvement of vascular enhancement with low kilovoltage settings. *Radiology* 2006; **241**: 899–907. doi: [10.1148/radiol.2413040128](https://doi.org/10.1148/radiol.2413040128)
39. Funama Y, Awai K, Nakayama Y, Kakei K, Nagasue N, Shimamura M, et al. Radiation dose reduction without degradation of low-contrast detectability at abdominal multisecton CT with a low-tube voltage technique: phantom study. *Radiology* 2005; **237**: 905–10. doi: [10.1148/radiol.2373041643](https://doi.org/10.1148/radiol.2373041643)
40. Huda W, Scalzetti EM, Levin G. Technique factors and image quality as functions of patient weight at abdominal CT. *Radiology* 2000; **217**: 430–5. doi: [10.1148/radiology.217.2.r00nv35430](https://doi.org/10.1148/radiology.217.2.r00nv35430)
41. McCollough CH, Primak AN, Braun N, Kofler J, Yu L, Christner J. Strategies for reducing radiation dose in CT. *Radiol Clin North Am* 2009; **47**: 27–40. doi: [10.1016/j.rcl.2008.10.006](https://doi.org/10.1016/j.rcl.2008.10.006)
42. Szucs-Farkas Z, Verdun FR, von Allmen G, Mini RL, Vock P. Effect of X-ray tube parameters, iodine concentration, and patient size on image quality in pulmonary computed tomography angiography: a chest-phantom-study. *Invest Radiol* 2008; **43**: 374–81. doi: [10.1097/RLI.0b013e3181690042](https://doi.org/10.1097/RLI.0b013e3181690042)