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Diagnostic quality of CT pulmonary angiography in pulmonary thromboembolism: A comparison of three different kV values

Authors' Contribution:
Study Design A
Data Collection B
Statistical Analysis C
Data Interpretation D
Manuscript Preparation E
Literature Search F
Funds Collection G

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Background: Our purpose was to evaluate the effectiveness of different kilovolt (kV) uses in computed tomography pulmonary angiography (CTPA) in the diagnosis of pulmonary thromboembolism (PTE). We also aimed to establish the optimal kV value and investigate the possibility of obtaining appropriate imaging quality with minimal radiation dose.

Material/Methods: We compared 120, 100, and 80 kV CTPA for 90 patients in whom PTE was clinically considered. The examinations were carried out using a 128 multislice CT device (Definition AS, Siemens Medical Solutions, Forchheim, Germany). Each kV value was used on 30 patients in 3 groups. Patients in all groups were compared with respect to the mean radiation dose they received, pulmonary arterial attenuation values, image quality, and motion artefacts.

Results: With respect to pulmonary arterial attenuation values, imaging with 80 kV yielded significantly higher values ($p<0.05$). However, no difference was found between 120 kV, 100 kV, and 80 kV with respect to image quality. Similarly, no significant difference was detected between the groups with respect to pulmonary artery contrasting and motion artefacts. Statistically significant differences were present in DLP values and effective dose among all 3 groups ($p<0.001$).

Conclusions: Using 80 kV as the low value in CTPA imaging for patients pre-diagnosed with PTE will increase the density of pulmonary arteries and decrease the amount of radiation received.

Key words: **computed tomography pulmonary angiography • kilovolt • radiation**

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Background

Pulmonary thromboembolism (PTE) is a common complication of lower extremity deep vein thrombosis [1]. If not treated, it has high recurrence, high mortality and morbidity rates, and is responsible for 10% of hospital fatalities [2]. Depending on concomitant diseases, clinical signs may be masked and diagnosis becomes difficult [1]. Catheter pulmonary angiography has been the gold standard in diagnosis. However, the mortality rate of the method is approximately 0.5% and its morbidity is 1% [3]. Its use is further limited by its invasiveness, costliness, and inavailability [4].

With the advent of multislice computed tomography (MSCT) devices, a new era began in computed tomography (CT) angiography applications. Invasive diagnostic practices gave way to non-invasive CT angiographic ones. At present, the most common method used in PTE diagnosis is the CT pulmonary angiography (CTPA) [5].

As the number of slices obtained in multi detector CTPA is higher, the dose with CTPA is higher than for other CT applications and it is possible to decrease the kilovolt (kV) value to do the same with the radiation dose received [6,7]. Thus, using the lowest kV value in CTPA that will not affect the sensitivity of PTE diagnosis may help decrease the radiation dose received.

Our aim was to compare 3 different kV protocols for CTPA applications and to determine a radiation dose to use for routine CTPA value. To the best of our knowledge, there is no other study in the literature that has compared 3 different kV values.

Material and Methods

Patients

Subjects were 90 patients referred for CTPA between August 2011 and February 2012 with clinical suspicion of PTE. The evaluation was conducted prospectively. Written consent was obtained from all participants. Patients were consecutively allocated to 3 groups. Patients with 1 or more conditions known to present a counterindication for CTPA – known contrast material allergy, renal dysfunction (serum creatinine >1.5 mg/dl), pregnancy, respiratory problems, poor general condition, hyperthyroidism, and epilepsy – did not undergo the procedure. Approval was obtained prior to the study from the local university ethics board.

CT scanning and Interpretation

In our study, CTPA was conducted by using 3 different kV values (120, 100, and 80) among patients with PTE pre-diagnosis. For each kV value, we evaluated radiation dose, pulmonary artery enhancement, image quality, and motion artefacts. CT scanning was conducted by using a 128-slice CT device (Definition AS, Siemens Medical Solutions, Forchheim, Germany) and thorax CT angiography protocol. MSCT parameters were 300 ms rotation time, 128×0.6 mm collimation and 1 mm slice width, and pitch value was 1.0–1.2. Each study group received a different kV value: 120 in Group A, 100 in Group B, and 80 in Group C. Tube current was established for all patients based on 100 mAs reference value and using the CareDose4D (Siemens) method. Scan time, delay time, and injection speed were assessed in all patients to calculate total contrast volume. For most patients, a mean total of 50–60 ml contrast material (370/100 mg/ml iopromide, Ultravist; Schering, Berlin, Germany) was administered with an automatic injection at a speed of 5 ml/sec. Following contrast material, 30 ml serum physiologic was given at a bolus dose of 5 ml/sec. For contrast material and saline administration, 2-headed automatic injection (Stellant, Medrad, Indianola, USA) was used. Using the ‘bolus tracking’ method, scanning was initiated automatically and 120 HU was taken as the triggering value for the ROI inserted in the main pulmonary artery. Slices in the craniocaudal direction were obtained from the thorax entry to the diaphragm level.

Evaluation and interpretation of the images

Postprocessing was conducted with Leonardo (Leonardo, Siemens Medical Solutions, Forchheim, Germany) software. PA density measurements were made from 0.6-mm wide axial CTPA images. Image quality sufficiency, motion artefacts, and contrasting sufficiency in pulmonary arteries were assessed in the images. As CTPA examinations are usually performed in emergencies, body-mass index of most patients was not measured. Therefore, subcutaneous fat tissue thickness was used to assess the effects of body fat on CTPA quality. For each patient, subcutaneous fat tissue thickness was measured at the posterior vertebral colon level in slices passing from the main pulmonary artery level. The association between subcutaneous fat tissue thickness and pulmonary arterial attenuation values was examined. CTPA images were evaluated in randomized order by 2 expert radiologists, independently, and blinded to the patients’ clinical data. Intra- and interobserver agreement for the pathological findings and image quality were evaluated in all groups.

Segments with thrombus in pulmonary arteries were defined. Concomitant findings such as pleural effusion or pulmonary infarct were recorded. To evaluate central pulmonary arterial attenuation, a 2-cm^2 diameter region of interset (ROI) was used. Attenuation of peripheral pulmonary arteries was evaluated by performing measurements in the segmental or subsegmental arteries in apical and basal sections. For apical sections, the region between the upper and lower boundaries of the aortic arch was selected. For basal sections, the region

Table 1. Image quality characteristics was assessed subjectively using a five-point scales.

Scale and Score	Description
Image quality	
1	Very bad, no diagnosis possible
2	Low, confidence in making diagnosis degraded
3	Moderate but sufficient for diagnosis
4	Good
5	Excellent, enabling excellent differentiation of even small structures
Pulmonary arterial enhancement	
1	None, no diagnosis of PE possible
2	Slight
3	Sufficient
4	Good
5	Excellent
Motion artefacts	
1	Massive, no diagnosis possible
2	Definite, establishment of diagnosis impeded
3	Definite but image sufficient for establishment of diagnosis
4	Slight
5	None

between the inferior pulmonary veins and the diaphragm was assessed. Owing to their minimal diameter, the peripheral arteries and their attenuation were assessed by using 3-mm^2 ROI. The assessment was conducted by only using transverse sections. The examination involved CT angiography (window width 700 HU, window level 80 HU) and lung parenchymal (window width 1200 HU, window level – 600 HU) windows.

Image quality, pulmonary artery contrasting, and motion artefacts were assessed by using a predefined subjective assessment scale (Table 1) [8]. Image quality was assessed by considering the mediasten, lungs, main pulmonary artery, lung parenchyma, and upper abdominal structures other than the liver.

To estimate the effective dose received by CTPA, we used the method recommended in the handbook for quality criteria in CT by the European Study Group [9]. In this method, the effective dose is derived by multiplying the dose-length product (DLP, mGy.cm) with a transformation coefficient for the anatomical area examined (e.g., the chest is k=0.017 $\text{mSv}\cdot\text{mGy}^{-1}\cdot\text{cm}^{-1}$). The dose-length product is an indicator of the dose received by the patient throughout the length of the scan. During scanning, the device automatically identified the mAs amount based on section thickness and reference mAs value. The DLP values used to calculate the effective dose were obtained through the protocol automatically given by the device for each CTPA scan.

Statistical analyses

Statistical analyses were conducted by using the SPSS for Windows (version 15.0) package. P values below 0.05 were considered statistically significant. The chi squared test was used to determine whether there was a difference between the sex distribution in groups. Other parameters were compared by using 1-way ANOVA and post hoc Tukey tests.

Results

Intra- and interobserver agreement rates achieved by the 2 radiologists were 97% and 94.5%, respectively.

Patient charesteristics

A total of 90 patients aged between 24 and 89 years were assessed. The mean age was 63.23±15.36 years. With respect to age distribution, no statistically significant difference between the groups was detected ($p>0.05$). Sex distribution was similar between groups ($p>0.05$). Sex distribution and mean age in groups are shown in Table 2. Mean

Table 2. Mean age and gender distribution of groups.

		A Group	B Group	C Group
Subjects, n		30	30	30
Gender, n (%)	Female Male	13 (43.3) 17 (56.7)	16 (53.3) 14 (46.7)	18 (60) 12 (40)
Age (years), mean±SD		66.1±12.1	60.8±18.5	62.8±14.8

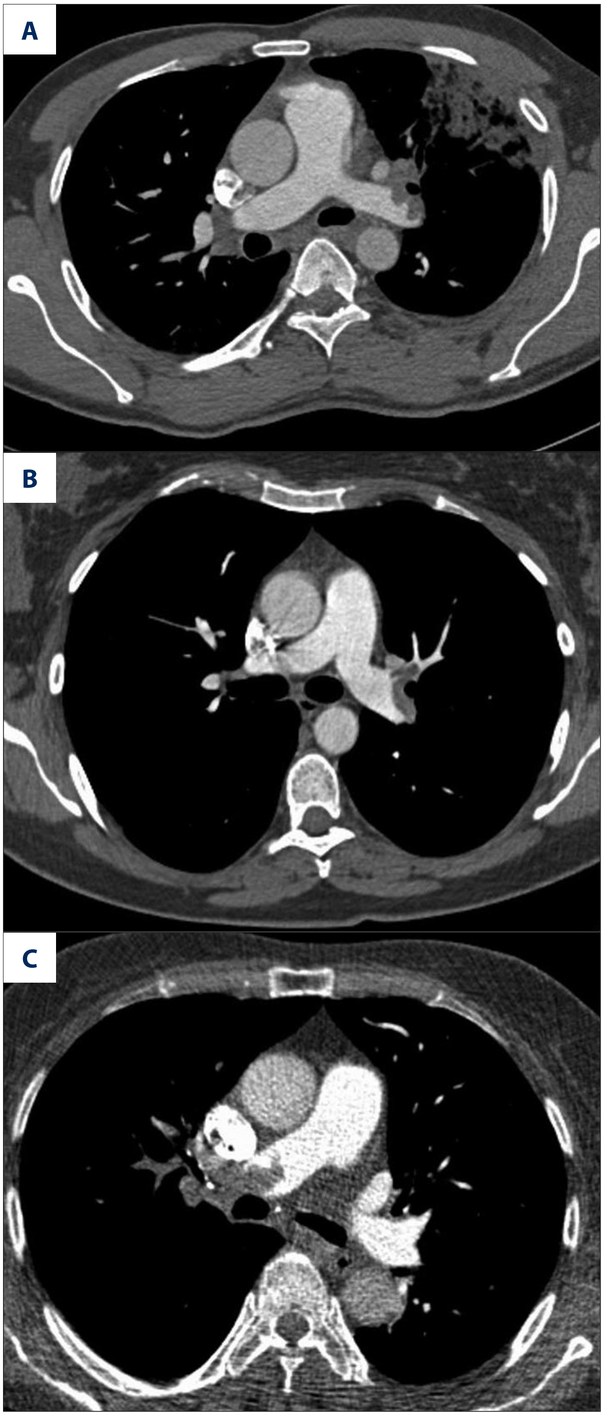

Figure 1. Axial thorax CT images show the pulmonary artery embolism (same window with and level value) (**A**) with 120 kV protocol, (**B**) with 100 kV protocol, (**C**) with 80 kV protocol.

subcutaneous fat tissue thickness was 16.71±8.82 mm in Group A, 16.05±7.02 mm in Group B, and 20.05±8.81 mm in Group C. No significant difference was observed between groups (p>0.05).

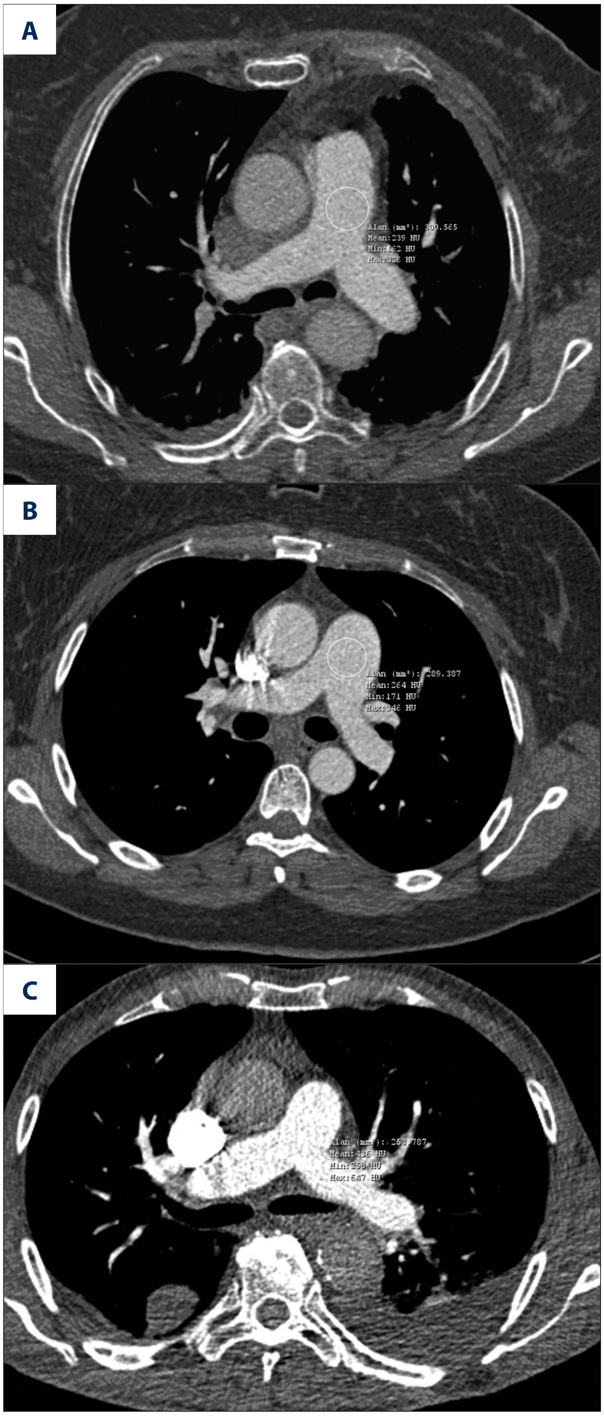

Figure 2. Axial thorax CT images show the image quality of main pulmonary artery (**A**) with 120 kV protocol, (**B**) with 100 kV protocol, (**C**) with 80 kV protocol.

Pathological findings

The CTPA scanning showed thrombus in the central pulmonary arteries of 4 patients (44.44%) and peripheral pulmonary arteries of 15 (16.66%) (segmental and subsegmental branches)

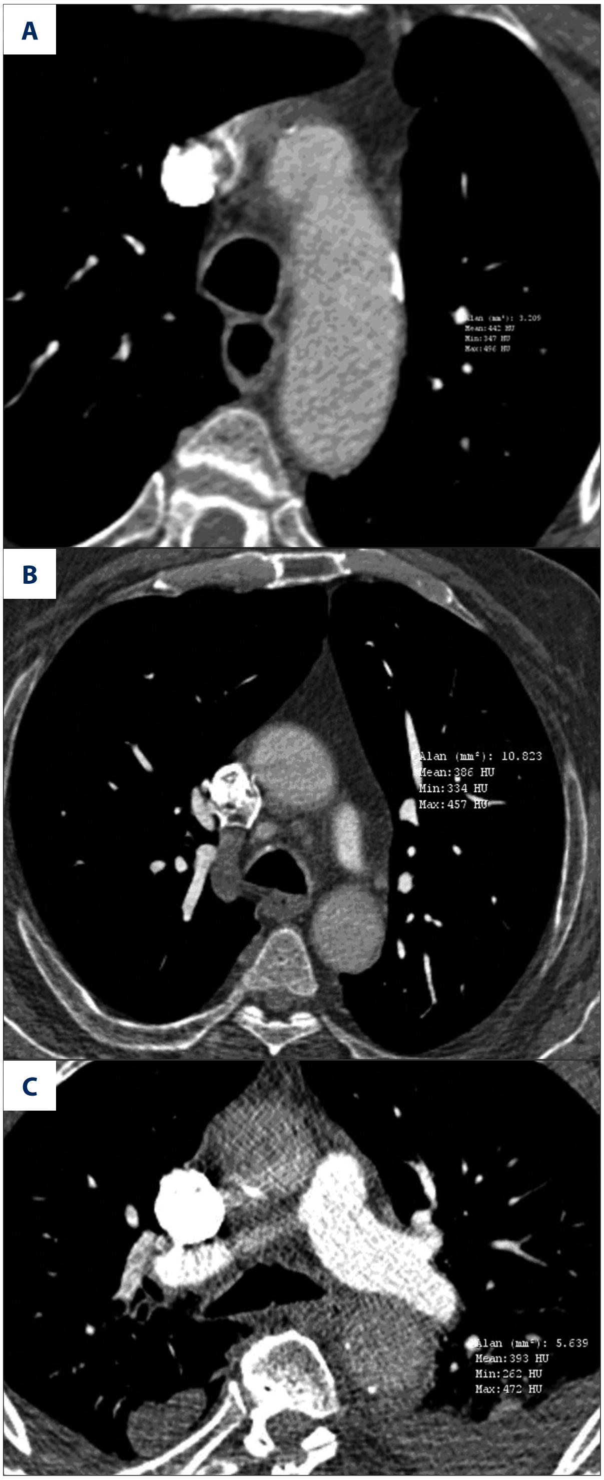

Figure 3. Axial thorax CT images show the density of the left-sided apical segment of pulmonary artery (**A**) with 120 kV protocol, (**B**) with 100 kV protocol, (**C**) with 80 kV protocol.

(Figure 1). One patient had a peripheral pulmonary arterial aneurism. An increase was noted in the main pulmonary artery and right-left pulmonary artery diameters in 36 patients (40%).

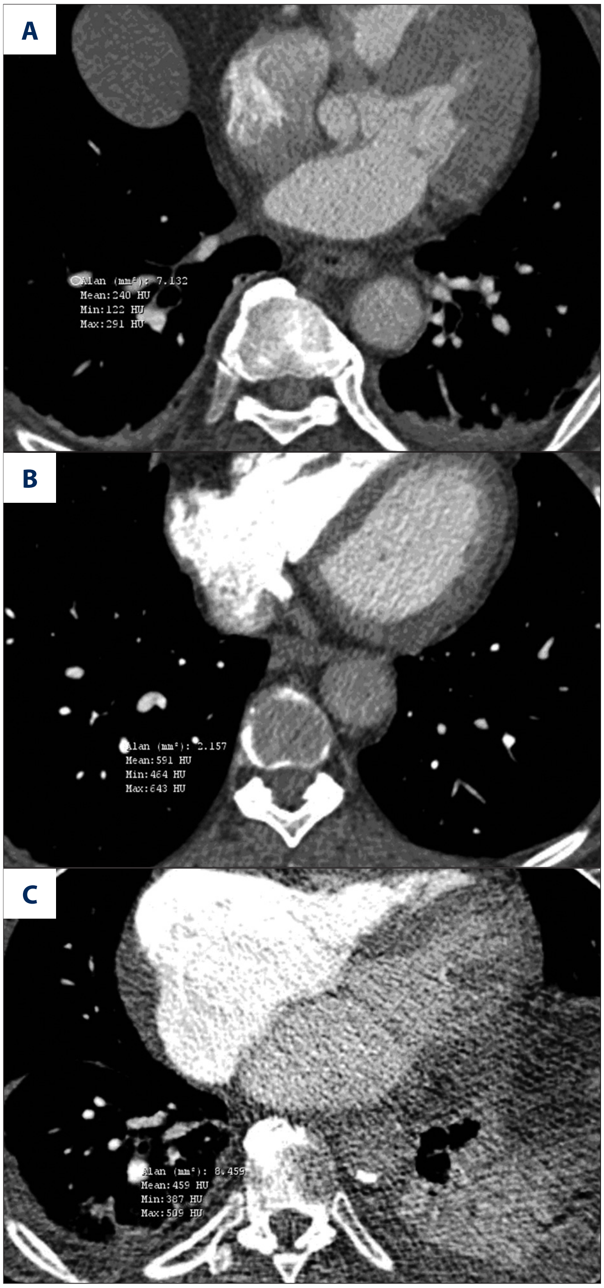

Figure 4. Axial thorax CT images show the density of the right-sided basal segment of pulmonary artery (**A**) with 120 kV protocol, (**B**) with 100 kV protocol, (**C**) with 80 kV protocol.

Assessment of pulmonary arteries

Mean density value in the main pulmonary artery and HU values in all peripheral arteries were highest in the scans of Group C and lowest in those of Group A (Figures 2–4). In all segments, a significant difference existed between Groups A and C and Groups B and C ($p<0.05$). The mean density value in the main pulmonary artery, maximum density values in the

Table 3. Comparison of pulmonary artery density, characteristics of image quality, radiation doses between groups.

	A Group	B Group	C Group	p-Value
Pulmonary artery density (HU)				
Main pulmonary artery	309.5±79.1	381.7±124.0	477.3±193.3	A–C→ p<0.001, B–C→ p 0.026
Apical pulmonary artery	369.7±88.7	463.9±127.0	578.1±271.1	A–C→ p 0.001, B–C→ p=0.042
Basal pulmonary artery	357.9±88.1	449.6±123.0	565.3±248.7	A–C→ p<0.001, B–C→ p 0.025
Characteristics of image quality				
Image quality	4.8±0.2	4.7±0.4	4.6±0.6	p>0.05 (between all groups)
Enhancement	4.5±0.6	4.7±0.4	4.6±0.7	p>0.05 (between all groups)
Motion artefact	4.9±0.1	5±0	5±0	p>0.05 (between all groups)
Radiation doses				
DLP (mGy.cm)	277.4±67.7	144.4±34.0	68.4±10.3	p<0.001 (between all groups)
Effective dose (mSv)	4.7±0.5	2.5±0.3	1.2±0.1	p<0.001 (between all groups)

peripheral pulmonary arteries at the aortic arch level, measurements made from basal level pulmonary arteries, and p values are presented in Table 3.

The lowest image quality assessment scores were obtained in Group C protocol. Although no significant difference was found among all groups (between Groups A and B, p=0.321; between Groups A and C, p=0.182; and between Groups B and C, p=0.266), 2 scans were evaluated as grade 3 in Group C. In Groups A and B, the CTPA of all patients were in grades 4 and 5. In the assessment of pulmonary artery contrasting, the mean value was above 4.5 in all 3 groups, and no significant difference was seen among them (p>0.05). Similarly, motion artefact was not significantly different across groups (p>0.05) (Table 3).

Amount of radiation dose

Statistically significant differences were detected in DLP values and effective dose among all 3 groups (p<0.001) (Table 3).

Discussion

PTE is often a complication of lower extremity and abdominal deep vein thrombosis. CTPA is the gold standard used for PTE diagnosis in most clinics due to the wide availability of MSCT devices [10]. In comparative studies with lung scintigraphy, CTPA has been found to have better sensitivity value [11]. It also has the advantage of revealing pathologies of other structures in the thorax [3,4,1]. In a prospective study with 158 patients, Qanadli et al. used pulmonary angiography as the reference method and found CTPA sensitivity to be 90% and its specificity to be 94% [13].

The radiation dose received during the scan presents a serious problem, particularly to patients with non-life-threatening pulmonary embolism, those with a low clinical probability of pulmonary embolism, and young female patients [8]. Changing certain technical parameters may help reduce radiation dose without significantly affecting diagnostic quality. This may be achieved by reducing parameters such as tube current (mA) and gantry rotation time (s), kV, the scanned area, using automatic tube current modulation, and increasing table speed.

CTPA uses values between 80 and 140 kV. Keeping all other factors constant, decreasing the kV value from 120 to 80 would reduce the radiation dose by at least 60%. However, decreasing the kV value strengthens the contrast in the image and increases noise. Consequently, SNR declines because the relative increase in noise is larger than the increase in image contrast. At the same time, diagnostic image quality can be maintained even when typical kV values of CTPA are reduced to 100 and even to 80 kV for some patients [10]. This is due to the increased photoelectric effect in low kV values. Reducing kV from 120–140 to 80 increases X-ray attenuation by 1.6 times and 2 times, respectively [10].

Previous studies have shown that contrast material attenuation significantly increases with the low kV technique, and vascular opacification becomes more significant as a result [8]. However, as body mass increases in low kV scans, image noise also significantly increases. This presents an important problem in thick parts of the body such as the abdomen. However, low kV uses do not present a problem in lungs, where there is a significant density difference between alveoli and the surrounding interstitium and vascular structures. X-ray attenuation and absorption is significantly lower in alveoli. This increases the visibility of neighboring parenchymal and vascular structures [8].

In a study of single detector spiral CT using 140 kV and 175 mAs as opposed to 100 kV and 125 mAs in 2 groups, Weidekamm et al. found significantly higher attenuation values in central and peripheral pulmonary arteries with a 100 kV protocol than with 140 kV (mean density value in main pulmonary arteries is 268 HU with the 140 kV technique and 379 HU with the 100 kV technique) [8]. The difference is greater in peripheral arteries than in the main pulmonary artery. This may be due to peripheral arteries being exposed to the partial volume effect between peripheral lung parenchyma and venous lumen. In a different study, researchers kept the mAs value constant in aortoiliac CT angiography and compared 120 and 100 kV. They concluded that vascular density was significantly higher in the 100 kV protocol (432±80 HU) than in 120 kV scans (333±90 HU). In addition, patients received significantly smaller doses of radiation in scans with 100 kV [14]. In our study too, the mean density value in the main pulmonary artery and maximum density values in all peripheral arteries were highest in 80 kV scans and lowest in 120 kV scans. In all segments measured, significant differences existed between the density values of Group C and those of Groups A and B (<0.05).

In the same study, Weidekamm et al. did not find a significant difference between image quality in the 2 groups. In lower kV values, noise increases with vascular density (signal); consequently, the optimal signal-noise ratio is maintained. As the signal-noise ratio will stay approximately at the same level, kV values may be decreased without significant deterioration in image quality [8]. Weidekamm et al. found that to reduce the effects of increased noise and compensate for the elevated attenuation in pulmonary veins, increasing the width in mediastinal window settings is useful in assessing the images [8]. A recent study by Szucs-Farkas et al. also revealed that the intra-individual comparison of diagnostic accuracy with normal dose (120 kV) and simulated low-dose (80 kV) pulmonary CTA protocols were not significantly different under experimental conditions [15]. In our study, we gained a similar image quality with the 80 kV protocol. Only in the group where 80 kV was used, 2 scans were evaluated as having moderate image quality (grade 3), which compromises diagnostic reliability.

Using the same patients as their control group, Fanous et al. kept other parameters constant, and compared image quality and radiation doses in 32 patients who underwent CTPA scans with 100 and 120 kV. Their results showed an approximately 29% increase in signal in low kV scans; the radiation dose (DLP) was 37% less, with no serious compromise in diagnostic image quality (604.46 mGy × cm in 120 kV and 379.26 mGy × cm in 100 kV). Based on their findings, they concluded that 100 kV may be used in CTPA scans for patients under 100 kg body weight [16]. In our study, in which we compared 3 different kV values, the highest DLP value was 417 mGy × cm in Group A, and the lowest value was 46 mGy × cm in Group C. DLP values in the 3 groups were statistically different ($p<0.001$). With respect to effective doses, the lowest radiation exposure was found in the 80 kV group.

The limitations of our study were the small number of patients and the randomization of patients according to body mass index, as most scans were taken in emergency situations.

Conclusions

To the best of our knowledge, this is the first study to compare 80, 100, and 120 kV values in patients clinically prediagnosed with PTE. We did not find a significant difference among all groups in respect to image quality. In our opinion, using 80 kV in CTPA scans for patients clinically prediagnosed with PTE enables an increase in pulmonary arterial density without compromising image quality and facilitates the identification of any thrombus. In addition, there will be a significant reduction in radiation dose.

Conflict of interest disclosure

The authors declare no conflicts of interest.

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