Diagnostic confidence and image quality of CT pulmonary angiography at 100 kVp in patients with high body weights

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Purpose

CT pulmonary angiography (CTPA) with 100 kVp tube energy is becoming more widespread, replacing the former routine protocols using 120 kVp or 140 kVp as the first-choice imaging modality to rule in or out pulmonary embolism (PE) (1-3). The most important reason to use lower peak tube voltage for CT angiography is to reduce the radiation dose to the patient, which is proportional to tube energy to the power of 2.4. As a secondary advantage, the attenuation in the contrasted vessels increases as the tube voltage gets closer to the k-edge of iodine.

High body weight (BW) and body mass index (BMI) can significantly hamper the efficacy of the low kVp technique by producing images with a high level of noise. Moreover, vessel attenuation in large patients is decreased compared with that in thin patients because of beam hardening. Increased noise and lower vessel attenuation inevitably leads to reduced contrast-to-noise ratio (CNR) in obese subjects, which might reduce diagnostic confidence to exclude PE (5, 6). Thus, CTPA with 100 kVp is usually restricted to patients weighing no more than 80-100 kg in many centers.

We are not aware of any data on the feasibility and quality of CTPA protocols at 100 kVp in large patients. Furthermore, no upper limit in BW or BMI has been established for the applicability of 100 kVp CTPA. Since the proportion of young obese adults is increasing in Western industrial countries and obese patients are at increased risk for developing PE, the number of CTPAs performed in this patient group is also expected to rise (10). These young individuals are more prone to developing radiation-related cancer than elderly patients because of the higher mitotic rate in their organs and their life expectancy.

The purpose of the current analysis was to assess the image quality and diagnostic confidence of CTPA using 100 kVp in various BW groups above 75 kg, with special emphasis on obese patients weighing more than 100 kg.

Materials and Methods

We retrospectively analyzed our database for patients with suspected PE and BW #100 kg (220 lbs), who underwent CTPA between September 2007 and April 2011. Of 123 consecutive patients fulfilling the criteria, 102 were examined with 100 kVp CTPA and 21 with 120 kVp CTPA. Although the major objective of the study was to analyze image quality of CTPA with 100 kVp, examinations with 120 kVp were not discarded, but kept for a rough comparison within the various BW and BMI groups.

CTPAs of 114 patients weighing 75-99 kg, who were examined between September 2008 and April 2011 with the 100 kVp CTPA protocol, were also included in the analysis. These patients were participants of a single-center prospective randomized study (Reduced Dose in Pulmonary Embolism Diagnosis, REDOPED), which compared diagnostic accuracy with CTPA at 100 kVp and 80 kVp in patients weighing <100 kg. We chose 75 kg as the lower threshold because, from our experience, image noise can become a limiting factor for image quality with 100 kVp CTPA only above this BW.

The Institutional Review Board accepted the study protocol and waived informed consent for this retrospective data analysis.

CT protocol

All patients were examined with the same 16-row CT scanner (Somatom Sensation 16, Siemens Medical, Forchheim, Germany) using real-time automatic tube current modulation (CareDose4D) at the "average" level. The tube voltage was set at 120 kVp in 21 patients with BW #100 kg and at 100 kVp in 216 patients. All other parameters of data acquisition (100 mAs quality reference tube current, 16 ´ 0.75 mm collimation, 0.5 s tube rotation time, 1.15 pitch) were kept constant.

One hundred milliliters of commercially available contrast medium with 300 mg/mL iodine concentration was administered intravenously at a rate of 4 mL/s followed by 20 mL saline at the same flow rate. Optimal enhancement of the pulmonary arteries was reached by using bolus tracking. Image acquisition was started 4 s after reaching 100 Hounsfield units (HU) in the pulmonary trunk.

Analysis of objective image quality

Circular regions of interest (ROIs) were placed in the center of the main pulmonary artery on the original 1-mm-thick transverse images and the attenuation (CT number) was measured (HU_{vessel}.). The standard deviations of the CT numbers were used as image noise. The background signal was measured in the paraspinal muscles at the level of the main pulmonary artery (HU_{backgr}.).Each measurement was performed at three different locations and the mean of the values was used for further calculations. Contrast-to-noise ratio (CNR) was computed as follows: CNR= (HU_{vessel} - HU_{backgr}.)/ noise.

Analysis of subjective image quality and diagnostic confidence

All CTPAs were randomized and independently evaluated on standard LCD monitors by three radiologists with CT experience of 4 years, 12 years, and 15 years, respectively, who were blinded to all patient data. Readers were asked to rate the overall image quality on the 1-mm-thick transverse slices on a five-grade scale (1 = bad, no diagnosis possible; 5 = excellent). Observers also reported their diagnostic confidence to detect or exclude

PE (1 = possible diagnosis; 2 = probable diagnosis; 3 = definite diagnosis). Readers were allowed to adjust window level and width during the evaluation at their own discretion.

Analysis of patient exposure and dose-independent change in image quality

The size-specific dose estimates (SSDEs), computed by multiplying volume CT dose index ($CTDI_{vol}$) by a correction factor, were used to assess patient exposure. The correction factor was defined by the reference diameter of the chest, which was calculated as the square root of the product of the anterioposterior and lateral chest diameters (10).

Statistical analysis

Subjective image quality ratings and confidence ratings were averaged over the readers, and the mean values were used for further analysis. Patients were grouped by their BW into three subgroups: 75-99 kg, 100-125 kg, and >125 kg. Objective and subjective image quality parameters, dose values, and diagnostic confidence were compared between the BW subgroups by using Kruskal-Wallis analysis of variance with post hoc tests. In a second step, the same comparisons were done between various BMI groups (<25, 25-30, >30 kg/m^2, i.e., underweight to normal weight, overweight, and obese patients). Interobserver agreement for the subjective image quality and confidence was assessed by the Spearman correlation analysis and the Kendall coefficient of concordance. Statistical tests were performed with Statistica software (StatSoft Inc., Tulsa, OK). The threshold for statistical significance was $P < 0.05$.

Results

Patients

Demographic and morphological data of the study population are summarized in Table 1. Most patients weighing #100 kg had BWs between 100 and 125 kg. The maximum BW was 150 kg in our collective. On the basis of BMI, 145 of 237 patients (61%) were obese (Table 2). CTPA was positive for PE in 48 patients and negative in 189 patients.

Image quality and diagnostic confidence in various BW groups

Attenuation in the main pulmonary artery at 100 kV was significantly higher in the 75-99 kg subgroup compared with the other BW groups (P=0.007 and 0.03), but there was no significant difference between the 100-125 kg and >125 kg groups (P= 0.892; Fig.1). The CNR was higher at lower BWs for all comparisons (P<0.001 and P= 0.046). While SSDE was significantly lower in the 75-99 kg subgroup than it was at higher BWs (P<0.006), there was no difference between the 100-125 kg and >125 kg subgroups

(P=1.0). Subjective image quality and diagnostic confidence were not different between the BW subgroups (P between 0.225 and 1.0).

When patient data in the 100-125 kg subgroup was compared at two tube voltages, vessel attenuation (P<0.001) was significantly higher at 100 kV than they were at 120 kV with similar CNR (P= 0.605; Fig.1). SSDE was higher at 120 kV than at 100 kV in both the 100-125 kg and >125 kg subgroups (P<0.001 and P= 0.029). There was no significant difference in subjective image quality and diagnostic confidence at the various kilovoltages in both subgroups (P between 0.081 and 0.289).

Image quality and diagnostic confidence in the BMI groups

At 100 kVp tube energy, CNR was significantly lower above 30 kg/m^2 than in the other BMI groups (P= 0.006 and P= 0.004; Table 2). SSDE was higher in obese patients compared with normal weight or overweight subjects. Subjective image quality was significantly worse in obese patients than in normal weight subjects (P = 0.025). Diagnostic confidence was no different among all three BMI groups (P = 0.105). In obese patients, the 100 kVp protocol provided higher vessel attenuation with similar CNR and lower SSDE compared with the 120 kVp protocol (Table 2).

Interreader agreement

The correlation of the ratings given for subjective image quality by the three independent readers was moderate (Spearman R between 0.35 and 0.59; P<0.001) with a Kendall coefficient of concordance of 0.363. For the diagnostic confidence, the Spearman R values ranged between 0.329 and 0.425 (P< 0.001) and the Kendall coefficient was 0.219.

Images for this section:

		All patients	Body weight groups			
			75-99 kg (n= 114)	100-125 kg (n= 101)	> 125 kg (n= 22)	*P*
Female/Male (n)	**100 kV**	55/162	33/81	18/70	4/10	<0.001
	120 kV	7/14	0/0	4/9	3/5	<0.001
	P	0.426	-	0.400	0.665	
Age (yrs)	**100 kV**	58.8±16.4	59.2±15.8	59.2±14.1	52.7±16.7	<0.001
	120 kV	55.5±17.8	-	56.6±15.3	53.6±18.5	<0.001
	P	0.479	-	0.998	1.0	
Weight (kg)	**100 kV**	97.3±16.3	85.0±6.5	107.0±7.2	136.0±9.2	<0.001
	120 kV	121.5±20.6	-	106.8±5.9	145.4±10.0	<0.001
	P	<0.001	-	1.0	0.061	
Height (cm)	**100 kV**	174.9±8.8	173.9±9.1	175.8±8.0	177.3±10.5	0.754
	120 kV	173.7±10.1	-	172.6±11.3	175.4±8.1	0.944
	P	0.657	-	0.898	0.993	
BMI (kg/m²)	**100 kV**	32.0±5.8	28.3±3.3	34.8±4.0	43.7±5.8	<0.001
	120 kV	40.6±7.5	-	36.3±5.3	47.5±4.8	<0.001
	P	<0.001	-	0.875	0.305	

Table 1: Demographic and morphologic data of the study population. Data are means and standard deviations except for gender. For each parameter, the third row contains P values for comparisons of patients examined with 100 kV or 120 kV. The far right-hand column shows P values for differences between various body weight groups. BMI, body mass index.

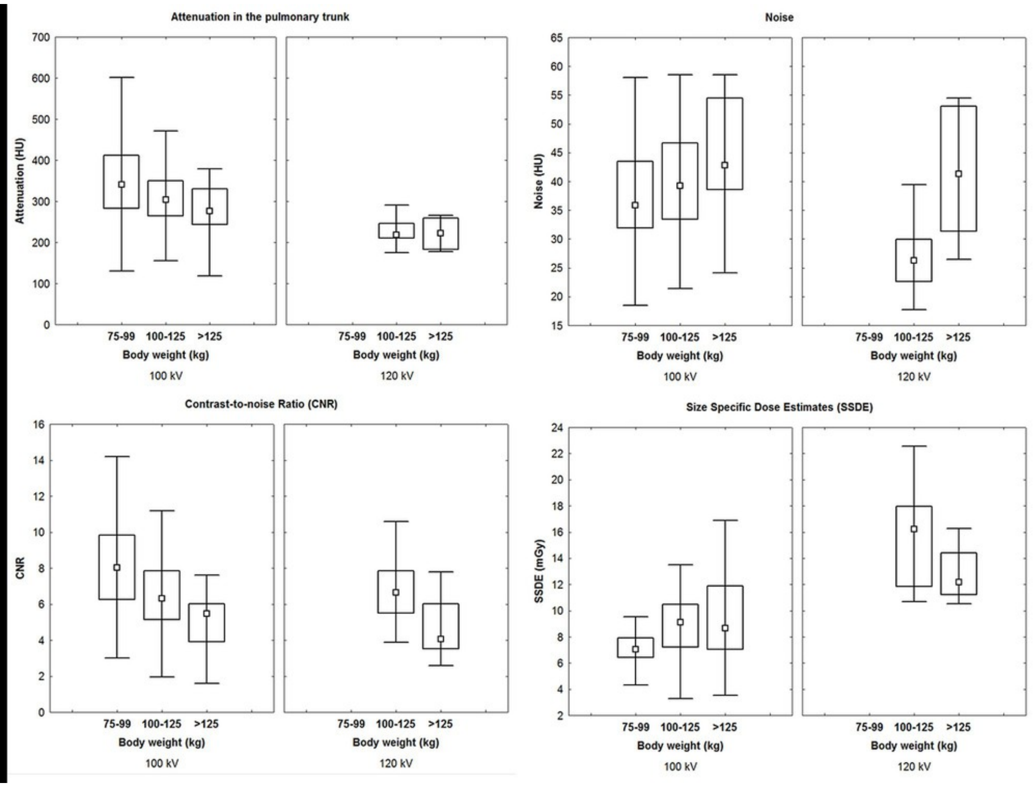

Fig. 1: Objective and subjective characterization of 216 CT pulmonary angiographies with 100 kVp tube voltage and of 21 examinations at 120 kVp. Patients are subgrouped on the basis of their body weights. The center point is for the median, the rectangle is for the 1st to 3rd quartile range, and the whiskers are for the range in each graph.

		BMI			
		<25 kg/m² (n= 17)	25-29.9 kg/m² (n= 76)	≥30 kg/m² (n= 145)	*P*
Female/Male (n)	**100 kV**	-/17	14/61	41/84	0.003
	120 kV	-	-/1	7/13	1.0
	P	-	1.0	1.0	
Weight (kg)	**100 kV**	81.0±7.0	86.3±7.4	106.1±15.3	<0.001
	120 kV	-	102.0±0.0	122.5±20.6	0.567
	P	-	0.773	<0.001	
BMI (kg/m²)	**100 kV**	24.1±1.0	27.5±1.4	35.7±4.8	<0.001
	120 kV	-	28.9±0.0	41.1±7.2	0.032
	P	-	0.998	<0.001	
Vessel attenuation (HU)	**100 kV**	343 [294; 366]	332 [276; 410]	311 [262; 363]	0.036
	120 kV	-	247 [247; 247]	218 [193; 260]	0.620
	P	-	0.210	<0.001	
Noise (HU)	**100 kV**	34.8 [31.7; 38.1]	36.2 [32.1; 43.8]	39.2 [33.3; 46.7]	0.036
	120 kV	-	24.3 [24.3; 24.3]	29.6 [24.6; 40.6]	0.409
	P	-	0.096	0.005	
CNR	**100 kV**	8.2 [7.4; 10.2]	7.9 [6.1; 9.8]	6.4 [5.1; 8.1]	<0.001
	120 kV	-	6.6 [6.6; 6.6]	5.6 [4.1; 7.8]	0.869
	P	-	0.569	0.226	
SSDE (mGy)	**100 kV**	6.9 [6.4; 7.1]	7.0 [6.2; 8.0]	8.4 [7.1; 10.3]	<0.001
	120 kV	-	19.4 [19.4; 19.4]	13.3 [11.5; 16.6]	0.187
	P	-	<0.001	<0.001	
FOM	**100 kV**	9.8 [8.3; 15.3]	8.4 [5.2; 14.1]	5.2 [2.9; 8.8]	<0.001
	120 kV	-	2.2 [2.2; 2.2]	2.7 [1.2; 4.0]	0.869
	P	-	0.116	<0.001	
Subjective image quality	**100 kV**	4.3 [4.0; 4.3]	4.0 [3.3; 4.3]	3.7 [3.3; 4.3]	0.019
	120 kV	-	3.3 [3.3; 3.3]	3.3 [2.7; 4.0]	1.0
	P	-	0.287	0.068	
Diagnostic confidence	**100 kV**	3.0 [2.7; 3.0]	3.0 [2.7; 3.0]	2.7 [2.3; 3.0]	0.105
	120 kV	-	2.3 [2.3; 2.3]	2.7 [2.2; 3.0]	0.610
	P	-	0.156	0.237	

Table 2: Patient characteristics, image quality, and diagnostic confidence in various BMI groups. Data for weight and BMI are mean ± standard deviation. Medians with the lower and upper quartiles are provided in brackets for objective and subjective image quality parameters and for diagnostic confidence. Tube voltage was set at 120 kVp in only one overweight patient and in no subject in the <25 kg/m2 group. Thus, a meaningful

comparison of data between 100 kVp and 120 kVp is only possible in obese patients. BMI, body mass index; SSDE, size-specific dose estimates; FOM, figure of merit.

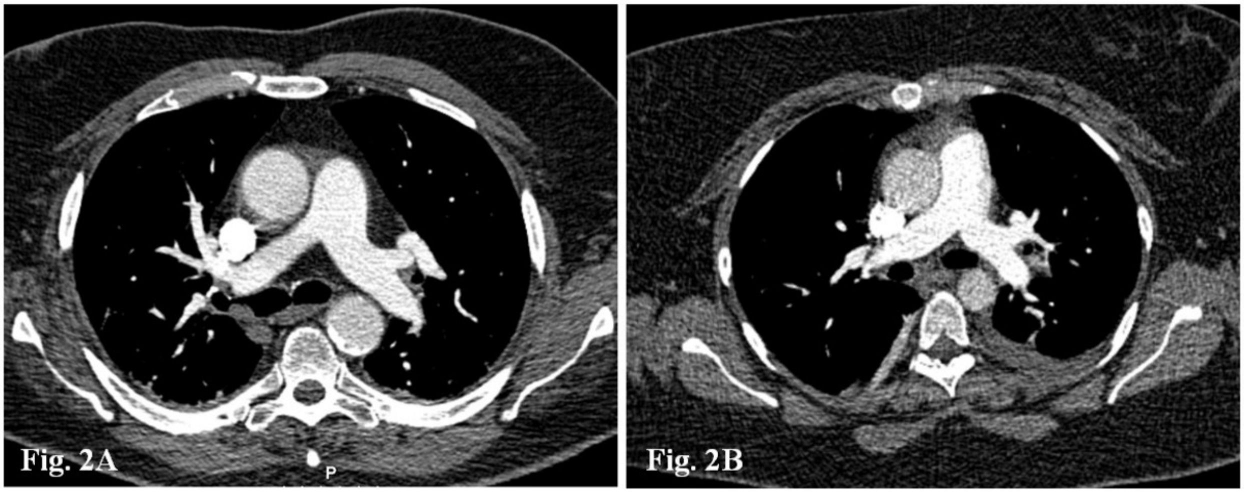

Fig. 2: Exemplary 1 mm thick transverse CTPA images at 100 kVp from our patient collective. The patients shown had a body weight of 109 kg (A) and 136 kg (B). For better comparison the window level was set at 100 HU and the window width at 500 HU for both images.

Conclusions

The results of this study show that despite reduced CNR as a measure of objective image quality, 100 kVp CTPA provides similar subjective image quality and diagnostic confidence to detect PE in patients who are below or above 100 kg. Moreover, the BMI-based data analysis did not show any significant difference in confidence between obese, overweight, or normal weight patients. These data suggest that the 100 kVp CTPA can safely be used in the surveyed BW range, which was 75 to 150 kg, although the number of patients weighing 125-150 kg was low (only 5 patients). To the best of our knowledge, this is the first investigation that targets image quality and diagnostic confidence with 100 kVp CTPA in patients with high BW or obesity.

The main limitations of our study are as follows:

1. This was a retrospective study analyzing a limited number of patients, especially in the >125 kg subgroup. The low number of patients with 120 kVp CTPA allowed for only a rough comparison with data at 100 kVp.

2. Our CT scanner used conventional filtered back projection for image reconstruction.

3. The experience of the three readers assessing subjective image quality was inhomogeneous.

We conclude that CTPA at 100 kVp tube voltage can be used in patients with BW of up to 125 kg with no significant deterioration of subjective image quality or confidence to exclude or detect PE. Although our rudimentary data suggested the utility of 100 kVp CTPA in the 125-150 kg BW range, these results need further justification in larger populations. We expect that the routine use of iterative image reconstruction will further expand the applicability of 100 kVp tube energy for CTPA.

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Personal Information

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