Iranian Journal of Medical Physics
ijmp.mums.ac.ir

Comparison of Image Quality of Low Voltage 64-slice Multidetector CT Angiography with the Standard Condition in Patients Suspected of Pulmonary Embolism

Mohammad Davoodi[1], Soudabeh Belash-Abadi[2], Seyed Hossein Aalaei-Andabili[3], Ali Kabir[4*]

1. Department of Radiology, Ahvaz Jondishapur University of Medical Sciences, Khuzestan, Iran
2. Ahvaz Jondishapur University of Medical Sciences, Khuzestan, Iran
3. Nikan Health Researchers Institute, Tehran, Iran
4. Minimally Invasive Surgery Research Center, Iran University of Medical Sciences, Tehran, Iran.

ARTICLE INFO

Article type:
Original Article

Article history:
Received: Dec 16, 2017
Accepted: Mar 27, 2018

Keywords:
Image Enhancement
Image Quality
Computed Tomography Angiography
Pulmonary Embolism
Radiation Dosage

ABSTRACT

Introduction: Reduction of peak kilovoltage (kV) setting has been a useful approach to d creating radiation dose; however, it may have varied effects on noise and the accuracy of diagnosis. Thus, we compared image quality between low (80 kV) and standard kilovoltage (100 kV) protocols.
Material and Methods: This triple blind non-randomized parallel quasi-experimental study was conducted on 140 cases of questionable pulmonary embolism.
Results: Image quality was twice as high as the standard protocol in the 80-kV group (odds ratio=2.08). Main, segmental, and subsegmental arteries showed significantly higher vascular enhancement (P<0.001) in the 80-kV group. Similarly, the mean number of measurable segmental arteries was significantly greater in the 80-kV group relative to the standard group. On the other hand, the mean of image noise was significantly higher in the 80-kV group in comparison with the 100-kV group (mean: 68.4 vs. 43.1; P<0.001). Finally, the mean of radiation dose received in the 80-kV group was significantly lower than that in the 100-kV group (mean: 0.94 vs. 2.43 mSv; P<0.001).
Conclusion: Lower radiation dose received and higher image quality, but worse image noise, in the 80-kV group compared to the 100-kV group present acceptable evidence in support of reduction of voltage in cases with the suspicion of pulmonary embolism. In these patients, therefore, it is recommended as a good strategy to be adopted in computed tomography angiography.

► *Please cite this article as:*
Davoodi M, Belash-Abadi S, Aalaei-Andabili SH, Kabir A. Comparison of Image Quality of Low Voltage 64-slice Multidetector CT Angiography with the Standard Condition in Patients Suspected of Pulmonary Embolism. Iran J Med Phys 2018; 15: 237-242. 10.22038/ijmp.2018.27829.1302.

Introduction

The age- and sex-adjusted incidence rate of pulmonary embolism (PE) has been 0.38 per 1000 persons during 2002-2012 [1]. However, PE is correctly diagnosed in only 9-35% of patients. Mortality rate for unrecognized PE patients has been reported about 80% more than PE patients receiving treatment [2]. Therefore, early and precise diagnosis of PE is highly critical [3]. After great progress in computed tomography (CT) angiography technology, CT pulmonary angiography (CTPA) has been considered the single first-line method for the detection of PE. However, radiation exposure is concerning, and unnecessary radiation exposure brings about many negative results, especially in young pregnant women with the suspicion of PE [3-5], which indicates the importance of CT radiation reduction [6, 7].

Reduction of peak kilovoltage (kV) setting is an effective approach to lowering radiation dose [8]. Although it has been argued that lowering the kilovoltage setting can undermine image quality, some studies have yielded discrepant results [8, 9]. Since there is not enough evidence regarding the effect of reduced kilovoltage setting on image quality and accuracy of PE detection in CT scan operators, we aimed to compare the quality of images between 100 kV and 80 kV protocols to provide evidence regarding safety and effectiveness of kilovoltage reduction.

Materials and Methods

This is the first phase of a diagnostic non-randomized triple blind parallel quasi-experimental study. All patients suspected of PE who presented to Golestan Hospital, Ahvaz, Iran, and signed the written informed consent were enrolled in the study. Indication for CTPA was determined according to clinical findings, laboratory tests, echocardiography, and X-ray results indicative of PE. The exclusion criteria included allergy

*Corresponding Author: Tel: +98-912-388-5570; Email: aikabir@yahoo.com

to contrast material, hyperthyroidism, renal failure, pregnancy, body weight > 100 kg, and refusing to sign the consent form.

The convenience sampling method was used for the selected participants. Considering α=0.05 and β=0.2, the percentage of images with excellent and good quality was postulated about 91% in the group receiving a higher voltage and 69% in the 80-kV group (based on our pilot study). Comparing two ratio formulas (ratio of images with excellent and good quality to all images), the sample size was calculated to be 140 cases (70 cases per group).

The participants were assigned to low kilovoltage (80 kV: intervention group) and standard kilovoltage (100 kV: control group) groups using -a non-randomized approach. In detail, we entered the patients presenting to the hospital during the first six to 100-kV group, and the patients visiting the hospital within the second six months were allocated to 80-kV group. No sample attrition was recorded during the study.

All the CT scans were performed by a single commercially available model (64 slice scanner, Somatom Sensation; Siemens, Germany, 2009). The contrast material was Omnipaque 300, and each patient received 50 ml of the contrast material. Flow rate was 5 ml/s, scan time was 6 s, and delay time (the time between injecting the contrast agent and beginning the scan) was 4 s. Milliampere varies according to cross section (45-135 mA), and it is determined by the CT scan device through the CARE Dose method. The minimum and maximum amperes were determined according to the records of the picture archiving and communication system (PACS).

Thickness of the slices (cuts) performed by a spiral CT scan device was 1 mm, and scan time, rotation time, and time of bed movement and rotation (pitch) were 6, 0.3, and 0.9, respectively. Moreover, collimation was 0.6 and kernel was B25. Window width and level were set at 700 HU and 80 HU.

The study was triple blind; patients knew that there were two protocols, but they were not informed of their own protocol. The radiologist who reported graphs was also blind to the used voltage. All the CT images were coded by a colleague who was not involved in obtaining and reporting the images or analyzing the data. Also, the kV displayed on the images was covered in PACS. The person who analyzed the data was also blinded to image codes.

The primary outcome measures were the number of measurable arteries in different segments of the lungs, pulmonary vascular enhancement, image noise (considering background image noise in the equation), and image quality score.

Image noise was objectively quantified by calculating the standard deviation of CT numbers in a homogenous region of interest (size: >1 cm^2; range: 1.1-1.7 cm^2) that was free of motion- or contrast material-induced artifacts and was located in the main pulmonary artery.

One expert radiologist, who was blind to demographic, clinical, image voltage, and other details reported in CT angiographies, assessed quality of the images according to the visual assessment score (Table 1).

For the estimation of chest cross-sectional area according to cm^2, half of the largest diameter of the chest was considered as chest radius. Then, it was exponentiated and multiplied to π (3.14). However, previous reports did not consider the effect of this variable.

For calculating each patient's total effective dose of radiation, we used the following formula: Dose-Length Product (DLP) * Conversion factor (Conversion factor of the chest is 0.017). We labelled this effective dose as He. The unit of He is millisieverts (mSv).

We used a researcher-made data collection form, which recorded demographics (i.e., age, gender, weight, and height), voltage, ampere, presence of PE, window level, window width, vascular arterial enhancement in different segments and subsegments of the lung, image noise, number of measurable segmental and subsegmental arteries in different parts of the lung, characteristics of the cases, diameter of the chest, smoking habits, job, concomitant diseases (comorbidities), image quality score, motion artifacts, received radiation dose, and technician name.

Table 1. Image quality score

Score	Label	Explanation
5	Excellent	Optimal enhancement at least at the subsegmental artery level to allow unambiguous diagnosis of the presence or absence of a clot
4	Good	Optimal enhancement at least at the segmental artery level to allow confident diagnosis of the presence or absence of a clot
3	Fair	Optimal enhancement but insufficient for diagnosis
2	Poor	Inadequate for diagnosis of the presence or absence of a clot
1	Non-diagnostic	No diagnosis possible

The collected data were analyzed by SPSS, version 17. The normal distribution of the data was assessed by Kolmogorov-Smirnov and Shapiro-Wilk test in addition to Q-Q plot. Categorical variables were expressed as frequency and percentage. Strength of association of categorical variables was expressed as odds ratio (OR) and 95% confidence interval (CI). In addition, mean, mode, standard deviation (SD), and standard error (SE) were used. Student's t-test and Chi-square test were run to compare the characteristics of the two groups. Also, Fisher’s exact and non-parametric tests were considered, if needed. Univariate general linear model was implemented for controlling for continuous confounders in the two groups (chest cross-section area) for the assessment of continuous outcomes, such as vascular enhancement and measurable arteries. P-value less than 0.05 was considered statistically significant.

Results

One hundred and forty patients were assigned to the two groups based on CT kilovoltage. Seventy patients (36 [51.4%] males) with the mean age of 46.92±17.8 years were allocated to the 80-kV group. Seventy patients (27 [38.5%] males) with the mean age of 46.22±17.6 years were assigned to the 100-kV group (Table 2).

Age, gender, weight, height, body mass index (BMI), the ward where the patient was admitted to (i.e., emergency or outpatient), time of referral (day or night), job, pack-year of smoking, PE, and concomitant diseases were not statistically significant between the two groups. Thus, the two groups were comparable regarding image quality indices. Some of these indices are shown in Table 2.

Despite the mentioned similarities, the only significant difference between the two groups was in chest cross-section area with the means of 754.3±165 and 825.6±169.8 cm^2 in the 80 kV and 100 kV groups, respectively (P=0.013; Table 3), indicating the non-matching of chest cross-section area between the two groups possibly because of non-random nature of our sampling.

Quality of images was evaluated by a radiologist. All the images in the low voltage group had a quality score of 4 (5.7%) or 5 (94.3%). However, 71% of the images obtained from the 100-kV group had a score of 5, and 23.2%, 4.3%, and 1.4% had scores of 4, 3, and 1, respectively. We evaluated the association between CT scan voltage and subjective image quality. We found that acceptable (good) quality of images (scores 4 and 5) was significantly more frequent in the low voltage group (80 kV); the P-value was conservatively significant (0.058), while the OR was 2.08 (95% CI: 1.74-2.47), suggesting a significant difference. Consistently, we found that the mean of subjective image quality score was significantly higher in images acquired at 80 kV compared to those obtained at 100 kV (4.94±0.23 vs. 4.64±0.64; P<0.001; Figure 1, Table 3).

Table 2. Basic characteristics of patients in the 80-kV and 100-kV groups

Variable		80-kV group	100-kV group
Number of patients		70	70
Female number (%)		34 (48.5%)	43 (61.4%)
Male number (%)		36 (51.4%)	27 (38.5%)
Mean age (SD), year		46.92 (17.78)	46.22 (17.56)
Patients with pulmonary embolism diagnosis (%)		15 (21.4%)	25 (35.7%)
Admitted ward, No. (%)	Emergency	37 (52.9%)	34 (48.6%)
	Intensive care unit	33 (47.1%)	36 (51.4%)
Referred at, No. (%)	Day	48 (68.6%)	48 (68.6%)
	Night	17 (24.3%)	22 (31.4%)
Mean of smoking pack (SD)		0.733 (0.744)	0.955 (0.505)
Mean body mass index (SD)		26.06 (4.72)	27.13 (5.26)

kV: kilovoltage, No.: number, SD: standard deviation

Table 3. Comparison of image quality between the 80-kV and 100-kV groups

Variable	80-kV group	100-kV group	P-value
Chest cross-section area, mean (SD), cm^2	754.3 (165)	825.6 (169.8)	0.013
Good subjective image quality (4 and 5)	100%	94.2%	0.058
Mean (SD) of subjective image quality	4.94 (0.23)	4.64 (0.64)	< 0.001
MPA enhancement (SD)	516.5 (129.1)	380.7 (121.6)	< 0.001
Mean (SD) enhancement of right USPA1	571.8 (133.7)	396.5 (135.9)	< 0.001
Mean (SD) enhancement left USPA	579.7 (135.7)	402.7 (132.3)	< 0.001
Enhancement of right USSPA2	524.3 (126.8)	363.3 (126.8)	< 0.001
Enhancement of left USSPA	535.7 (130.9)	375.6 (109.8)	< 0.001
Enhancement of right LSPA3	577.3 (121.3)	392.7 (128.4)	< 0.001
Enhancement of left LSPA	577.5 (126.1)	413.1 (124.7)	< 0.001
Enhancement of right LSSPA4	565 (114.7)	376.4 (137.8)	< 0.001
Enhancement of left LSSPA	543.7 (138)	402.6 (133.4)	< 0.001
Mean (SD) number of MSA5	19.5 (1.5)	18.1 (4)	0.008
Mean (SD) number of MSSA6	40 (4.7)	37.8 (8.4)	0.066
Mean (SD) of image noise	68.4 (15.8)	43.1 (9.1)	< 0.001
Radiation dose received	0.94 ± 0.36	2.43 ± 0.77	< 0.001

1-Upper segmental pulmonary artery
2-Upper subsegmental pulmonary artery
3- Lower segmental pulmonary artery
4- Lower subsegmental pulmonary artery
5-Measurable segmental artery
6- Measurable subsegmental artery
kV: kilovoltage, SD: standard deviation

Vascular enhancement was evaluated in various arteries; enhancement of the main pulmonary artery (MPA) was significantly (P<0.001) higher in the 80-kV group compared to the 100-kV group (Figure 1, Table 3).

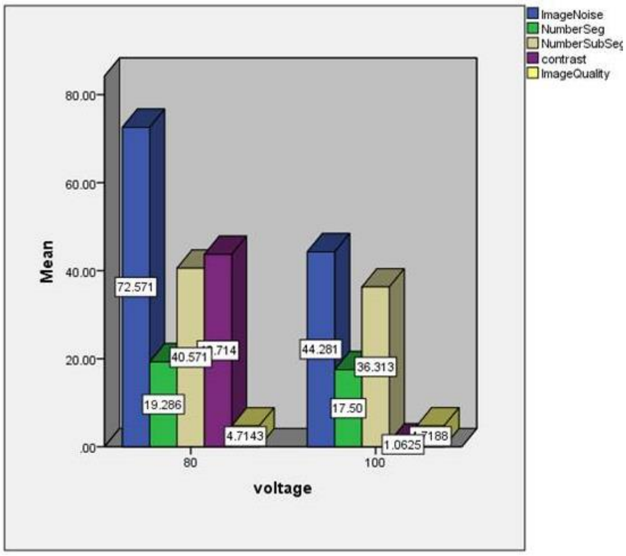


Figure 1. Comparing image quality, noise, contrast usage, and the number of measurable segmental and subsegmental arteries in cases undergoing 80 and 100 kilovoltage computed tomography angiography

Also, mean enhancements of the right and left upper segmental pulmonary artery (USPA), upper subsegmental pulmonary artery (USSPA), lower segmental pulmonary artery (LSPA), and lower subsegmental pulmonary artery (LSSPA) were significantly higher in the images obtained at 80 kV relative to those taken at 100 kV (P<0.001 for all; Figure 1, Table 3).

The mean number of measurable segmental arteries (MSA) was also significantly greater in the 80-kV group images compared to those in the 100-kV group (P=0.008; Figure 1). In contrast, the mean number of measurable subsegmental arteries (MSSA) did not differ significantly between the two groups, although it was borderline significant (P=0.066; Figure 1, Table 3).

On the other hand, mean image noise was 68.4±15.8 among images obtained using the 80 kV protocol and 43.1±9.1 using the 100 kV protocol (P<0.001; Figure 1). Neither weight nor BMI was associated with image noise score.

The means of radiation dose received in the 80-kV and 100-kV groups were 0.94±0.36 mSv and 2.43±0.77 mSv, respectively, which were significantly different (P<0.001; Figure 1), indicating 61.3% reduction in radiation exposure.

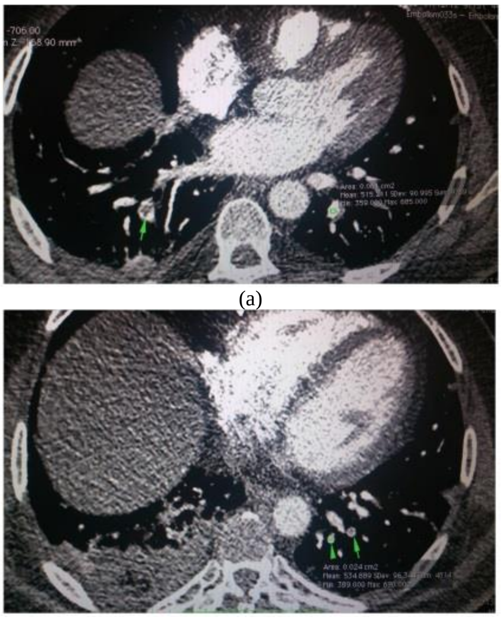
Despite increased noise, vascular enhancement improved using the 80 kV protocol (Figure 1). Moreover, embolism could be observed in subsegmental arteries in the 80 kV protocol (figures 2 and 3).

Because of significant difference in the chest area between the two groups, we repeated all the analyses considering this variable as confounding. The difference between the two groups remained significant for most variables like the mean enhancement of MPA, right and left USPA, USSPA, LSPA, LSSPA, radiation dose received (P<0.001 for all), mean image noise (P=0.001), and mean number of MSA (P=0.008). However, the mean number of MSSA remained non-significant (P=0.086) even after controlling for chest area using the univariate general linear model.

(a)

(b)

Figure 2. a) Axial view of a 26-year-old man with 100 kV protocol. Vascular embolism was detected in the right lower pulmonary artery. Vascular enhancement (= 330 HU) and image noise (= 33) were measured in the same vessel on the left side without embolism. B). The same patient from sagittal view



(a)

(b)

Figure 3. a) Axial view of a 44 year old man with 80 kV protocol. Vascular emboli was detected in right lower pulmonary artery. Vascular enhancement (= 515 HU) and image noise (= 90) were measured in the same vessel in the left side without emboli. b)Axial

view of the same patient with subsegmental posterior basal pulmonary artery embolism

Discussion

Various studies have suggested several strategies to attenuate radiation exposure during the imaging process. One of them is the adjustment of the CT scan operator voltage [10]. It has been suggested that the reduction of voltage from 120-100 to 80 kV could diminish radiation dose by about 40-60% without any significant changes in image quality [11, 12], which was confirmed by findings regarding PCTA using 80 kV instead of 100 kV, leading to 61% reduction in radiation dose (1-[0.94/2.43]) .

Based on our finding, the low voltage group had better subjective image quality despite higher noise. Similar to our findings, it has been stated that low voltage scanning does not hamper the detection of PE even in small and peripheral vessels [13]. On the other hand, it has been argued that reduced voltage can increase image noise, leading to the impairment of image quality [14]. However, it has been shown that the signal-to-noise ratio does not alter following reduction in voltage [15].

Heyer et al. [8] found that bolus tracking improved vascular enhancement, leading to boosted quality of images. It has been suggested that increased arterial enhancement by lowering voltage can compensate for the partial volume effect induced by thicker sections, producing more visible images [16]. Although it has been reported that the enhancement difference between the high and low kilovoltage approaches is more discernable between large and small vessels, in our study, the enhancement of all pulmonary vessels was significantly higher in images obtained by 80 kV. At least one study [13] has confirmed our results, suggesting the beneficial effects of low kV imaging on PE detection.

In contrast, another study claimed that vascular enhancement is not necessary for precise PE detection [17]. We found that the number of measurable segmental arteries was significantly higher in images obtained by 80 kV, but this difference was not significant for subsegmental arteries. Consistently, Schueller-Weidekamm et al. [13] reported similar results using low dose approaches. Since statistical tests confirmed that the groups were not significantly different in age, sex, BMI, admission ward (emergency or outpatient), time of referral (day or night), job, pack-year of smoking, PE, and concomitant diseases, it can be assumed that difference in voltage protocols can account for the differences in images.

The novelty of this study lies in the evaluation of the effect of lower voltage of CT angiography on image quality in cases with the suspicion of PE. The study showed that such attenuation in voltage saves patients from exposure to high radiation doses and increases image quality despite what we may expect. Despite deteriorated image noise, the radiation dose received was lower and image quality was improved in the 80-kV group in comparison with the 100-kV group.

Conclusion

Reduction of CT scan operator kilovoltage from 100 to 80 kV seems to be an effective strategy to reduce radiation exposure, which does not affect the detection of PE and leads to a safe imaging process that is beneficial for patients. In addition, despite increased noise, all image quality indices had improved. In this setting, low kilovoltage scanning can be used instead of standard kilovoltage operators.

References

1. Alotaibi GS, Wu C, Senthilselvan A, McMurtry MS. Secular trends in incidence and mortality of acute venous thromboembolism: the AB-VTE population-based study. The American journal of medicine. 2016;129(8):879-e19.
2. Nijkeuter M, Hovens MM, Davidson BL, Huisman MV. Resolution of thromboemboli in patients with acute pulmonary embolism: a systematic review. Chest. 2006 Jan 1;129(1):192-7.
3. Kuriakose J, Patel S. Acute pulmonary embolism. Radiologic Clinics. 2010 ;48(1):31-50.
4. Walsham AC, Roberts HC, Kashani HM, Mongiardi CN, Ng YL, Patsios DA. The use of computer-aided detection for the assessment of pulmonary arterial filling defects at computed tomographic angiography. Journal of computer assisted tomography. 2008; 32(6):913-8.
5. Moores L, Bilello KL, Murin S. Sex and gender issues and venous thromboembolism1. Clinics in chest medicine. 2004;25(2):281-97.
6. Karimizarchi H, Chaparian A. Estimating risk of exposure induced cancer death in patients undergoing computed tomography pulmonary angiography. Radioprotection. 2017; 52(2):81-6.
7. Chaparian A, Zarchi HK. Assessment of radiation-induced cancer risk to patients undergoing computed tomography angiography scans. International Journal of Radiation Research. 2018;16(1):107-15.
8. Heyer CM, Mohr PS, Lemburg SP, Peters SA, Nicolas V. Image quality and radiation exposure at pulmonary CT angiography with 100-or 120-kVp protocol: prospective randomized study. Radiology. 2007; 245(2):577-83.
9. Szucs-Farkas Z, Schibler F, Cullmann J, Torrente JC, Patak MA, Raible S, et al. Diagnostic accuracy of pulmonary CT angiography at low tube voltage: intraindividual comparison of a normal-dose protocol at 120 kVp and a low-dose protocol at 80 kVp using reduced amount of contrast medium in a simulation study. American Journal of Roentgenology. 2011;197(5):852-9.
10. Suess C, Chen X. Dose optimization in pediatric CT: current technology and future innovations. Pediatric radiology. 2002;32(10):729-34.
11. Sigal-Cinqualbre AB, Hennequin R, Abada HT, Chen X, Paul JF. Low-kilovoltage multi-detector row chest CT in adults: feasibility and effect on image quality and iodine dose. Radiology. 2004; 231(1):169-74.
12. LaBounty TM, Leipsic J, Poulter R, Wood D, Johnson M, Srichai MB, et al. Coronary CT angiography of patients with a normal body mass

index using 80 kVp versus 100 kVp: a prospective, multicenter, multivendor randomized trial. American Journal of Roentgenology. 2011 Nov;197(5):W860-7.
13. 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(3):899-907.
14. Albrecht MH, Bickford MW, Schoepf UJ, Tesche C, De Santis D, Eid M, et al. Beam-hardening in 70-kV Coronary CT angiography: Artifact reduction using an advanced post-processing algorithm. European journal of radiology. 2018; 101:111-7.
15. Wintersperger B, Jakobs T, Herzog P, Schaller S, Nikolaou K, Suess C, et al. Aorto-iliac multidetector-row CT angiography with low kV settings: improved vessel enhancement and simultaneous reduction of radiation dose. European radiology. 2005; 15(2):334-41.
16. Remy-Jardin M, Remy J, Artaud D, Deschildre F, Duhamel A. Peripheral pulmonary arteries: optimization of the spiral CT acquisition protocol. Radiology. 1997; 204(1):157-63.
17. Engelke C, Manstein P, Rummeny EJ, Marten K. Suspected and incidental pulmonary embolism on multidetector-row CT: analysis of technical and morphological factors influencing the diagnosis in a cross-sectional cancer centre patient cohort. Clinical radiology. 2006; 61(1):71-80.;25: 102−13.