European Journal of Radiology Open 7 (2020) 100254

Contents lists available at ScienceDirect

European Journal of Radiology Open

journal homepage: www.elsevier.com/locate/ejro

Pulmonary embolism: Low dose contrast MSCT pulmonary angiography with modified test bolus technique

Wael Hamza Kamr *, Amir Monier El-Tantawy, Mohamed M. Harraz, Ahmed Ibrahim Tawfik

Radiology Department, Mansoura University, Egypt

HIGHLIGHTS

- Test bolus technique increase the diagnostic quality score of the scans performed.
- Provides better evaluation of the pulmonary arteries and its subsegmental branches.
- Increase the main pulmonary artery average density, decrease average density of the aorta and pulmonary veins.
- Increase the confidence and accuracy rate of diagnostic examinations.
- Volume of IV contrast decreased by 40 % than in bolus tracking.

ARTICLE INFO

Keywords:
Pulmonary embolism
MSCT-pulmonary angiography
Test bolus
Bolus tracking

ABSTRACT

Purpose: This study aims to prove that the test bolus technique provides a better selective imaging study of the pulmonary arterial system in comparison to the automatic bolus-tracking technique.
Method: A prospective study included 600 patients, classified into 2 groups where each group consisted of 300 patients. In group A, we used the bolus tracking technique with 80−100 ml of contrast while in group B test bolus technique was used with 50 mL of contrast.
Results: It was clear that the Main PA average density was 260.5 HU in group A and increased to 320 HU in group B with P value < 0.002. The Ascending aorta average density decreased from 250 HU in group A to 130 HU in group B with P value <.001. The average score was increased by 35 % (from 1.75 in group A to 2.8 in group B with P value < .001). The Volume of IV contrast needed decreased by 40 % in group B compared to group A.
Conclusion: MSCTPA using test bolus method reduces the amount of the contrast used with better opacification of the pulmonary artery and its sub segmental branches in addition to reduced artifact.

1. Background

Pulmonary embolism (PE) is one of the acute chest pain and high risk mortality diseases. Its diagnosis and management should be done as soon as possible through a combination of clinical, laboratory and radiological investigations that play a main role in the diagnosis of PE. The imaging modality of choice is the pulmonary angiographic study by Multislice computed tomography (MSCTA) as it has a high sensitivity (82 %–97 %) and specificity (78 %–96 %) in the diagnosis of PE [1,2].

The MSCTA of the pulmonary arteries depends on the amount and timing of the contrast injection. There are two main technical methods; automatic bolus tracking and test bolus technique [3,4]. While the first method was routinely used, the second method was introduced subsequently. The difference between both methods is the way of estimation of the optimized time delay between contrast administration and image acquisition. [5]

The aim of this study is to prove that the test bolus technique provides a better selective imaging study of the pulmonary arterial system in comparison to the previously used standard automatic bolus-tracking technique.

2. Material and methods

Our prospective study included 600 patients (350 females and 250

* Corresponding author.
E-mail addresses: dr.waelkamr@gmail.coml (W.H. Kamr), amirmonirali@gmail.com (A.M. El-Tantawy), harrazharraz@live.com (M.M. Harraz), ahmedtawfik82@yahoo.com (A.I. Tawfik).

https://doi.org/10.1016/j.ejro.2020.100254
Received 28 July 2020; Accepted 24 August 2020

males with age ranging from 25 to 65 years and the mean age is 42 years) during the period from January 2017 to December 2018. The study was approved from the Institutional Review Board and an informed written consent was obtained from all patients.

All the patients were presented by clinical symptoms of PE such as acute chest pain, shortness of breath, desaturation associated with high risk factors of PE like having a history of previous chronic DVT, having acute DVT, previous surgery, or a high level D-dimer (positive D dimer test). Most of the patients presented at the emergency room while certain patients who were previously admitted as ICU patients or post-operative patients developed similar symptoms during the admission period. Informed consents had been obtained from all patients. Exclusion criteria included patients with high serum creatinine level, central line, as well as history of allergic reaction or those who refused the CT.

The patients are classified into 2 groups; each group consists of 300 patients with no specific selection. In **Group A**, we used the bolus tracking technique while in G**roup B**, the test bolus technique was used depending on the time of the contrast reaching to the pulmonary artery as well as the time of contrast reaching to the ascending aorta.

2.1. CT technique

CT pulmonary angiography examination was carried out using a SOMATOM Definition AS (64 detector) Multislice CT machine, Siemens/ Germany. All patients were scanned in supine position; head first, with the arms above the head. The imaging parameters were; field of view (FOV) 30 cm, voltage 120 KV. Tube current 80−100 mA, slice thickness 3 mm, increment interval 3 mm. Image reconstruction on slice thickness 1 mm and increment interval 0.5 mm for multiplanar coronal and sagittal reformate in addition to maximum intensity projection (MIP) reconstructed images.

Nonionic water soluble contrast media was injected intravenously by automatic injector through 18 gauge peripheral cannula in the right arm followed by 25−30 ml saline flushing. Contrast media used was VISIPAQUE contrast media with Iodine concentration 320 mg I/ml. There was no adverse reaction or complication noted in both groups. No extravasation was reported, as we used wide caliber cannula; patients with central line or difficult cannulation were excluded.

2.2. Automatic bolus tracking

This method is based on fixed selected axial cuts are taken at the level

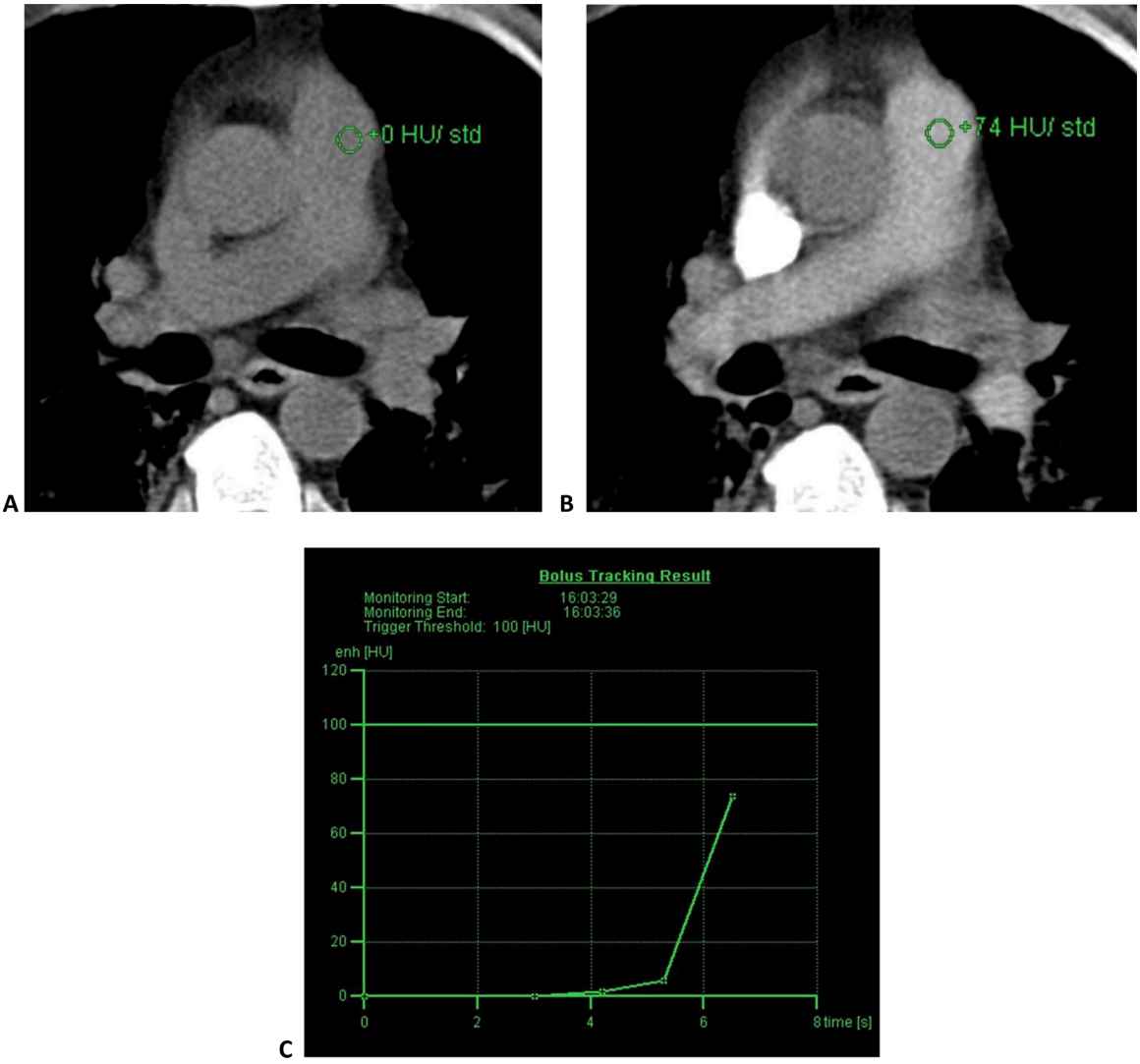


Fig. 1. Automatic bolus tracking, (A) axial non contrast image, the cursor seen at the main pulmonary artery before contrast administration, (B) axial post contrast image, the cursor shows increased contrast density within the main pulmonary artery. (C) Dynamic curve showing the progressive increase of the contrast density in main pulmonary artery.

of the main pulmonary artery. The curser is placed at the main pulmonary artery and the machine is adjusted to start full examination when the density of the contrast is double or reached 100 Hounsfield (HU) at the main pulmonary artery (real-time monitoring of the contrast) (Fig. 1).

In this method, the scanner and the injector start simultaneously and the first monitoring image is obtained at 5 s. Images are obtained every 1 s. When the region of interest reached the adjusted HU, breathing instructions are given by the technologist and full scan starts with a delay time 3–4 s to allow for the change from axial to helical scanner.

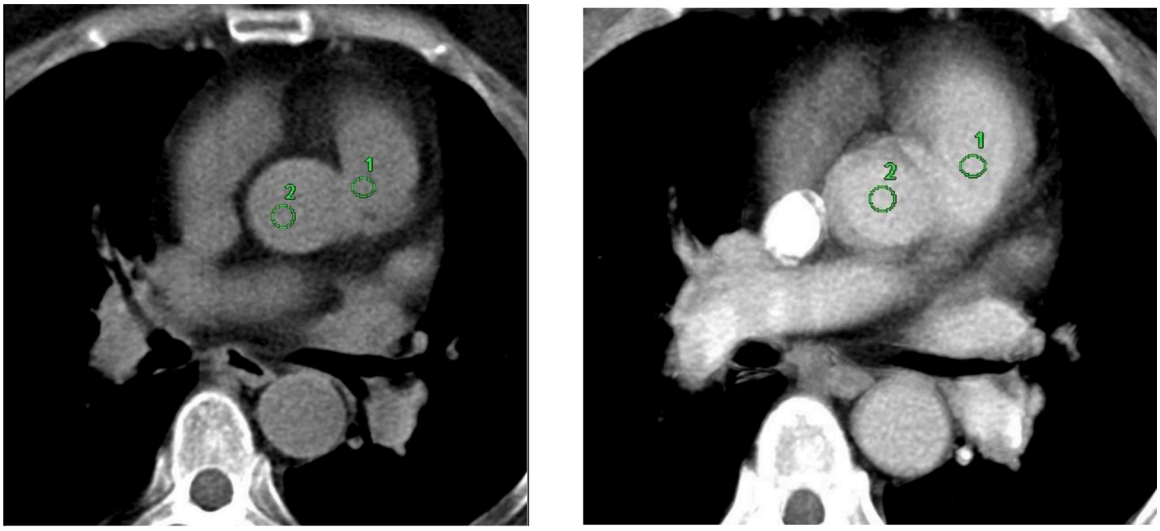
Contrast injection is continued along the whole time of scanning to be sure that adequate contrast is seen at the targeted vessels. The average time of scanning is 20 s that needs a larger volume of contrast (80−100 mL) at a rate of 5 mL/s.

2.3. Test bolus

In this method, a small amount of contrast 10 mL (initial test bolus) is injected initially to detect the accurate time of the contrast reaching the pulmonary artery and calculate the delay time between contrast injection and the start of the scan. The curser is seen at the pulmonary trunk and the time is estimated after contrast reached it.

The previous step is the routine test bolus technique; however in this study we added another step. We add another courser at the ascending aorta and also estimate the contrast time needed to reach the aorta as in the curve. The time difference between the pulmonary and aorta is calculated (Fig. 2).

For example, if the time to reach the PA is 10 s and the aorta is 16 s, then the time peak of the contrast at the pulmonary will be 6 s. There is a delay time 2−3 s to return to the starting point of examination. So, the total amount of the contrast (50−60-ml) should be injected within 9 s with a maximum flow rate 5.5 mL/s ($5.5 \times 9 = 49.5$ mL is the maximum amount can reach the pulmonary artery before reaching the aorta), so there's no need to add more contrast like in bolus tracking 80−100 ml. Then it is followed by 25−30 ml saline flush in a rate of 5 mL/s need 5−6 s. So the total time of examination, contrast injection and saline flushing will be maximum 15 s. So, the whole contrast, saline and examination finished before contrast reaching the aorta that need 16 s.



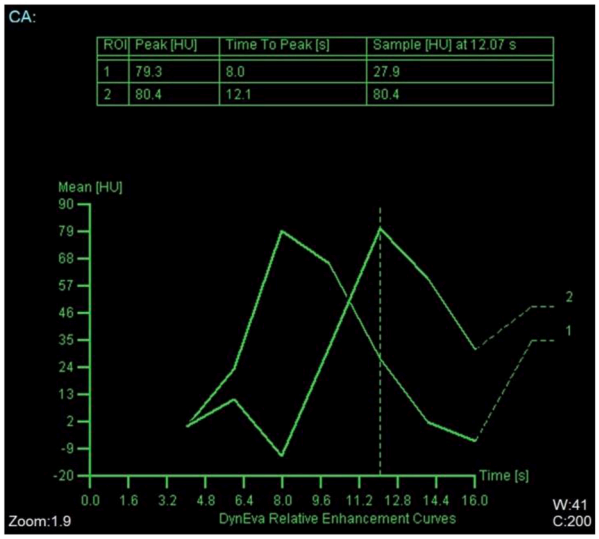


Fig. 2. Test bolus method, (A) axial non contrast image, the cursor seen at the main pulmonary artery and ascending aorta before contrast administration, (B) axial post contrast image, the cursor shows increased contrast density within the main pulmonary artery and ascending aorta. (C) Dynamic curve showing the time of contrast peak reached the main pulmonary artery 8 s. and the ascending aorta 12 s.

2.4. Image interpretation

Image interpretation was focused on the quality of the study and contrast enhancement based on the anatomical details; of the pulmonary artery, its branches and sub segmental branches. Moreover, the pattern of contrast opacification within the arteries, homogenous or non, adequate or non in addition to the appearance of contrast on the aorta and left sided heart or pulmonary veins were taken into consideration. The assessment was done subjectively and objectively for both groups (Figs. 3–6).

Measuring the contrast density in HU was done for quality assessment of the contrast opacification. The densities measured in the axial images at the main pulmonary trunk, the ascending and the descending aorta. The contrast density was measured at the target region with the cursor include most of lumen of each vessel.

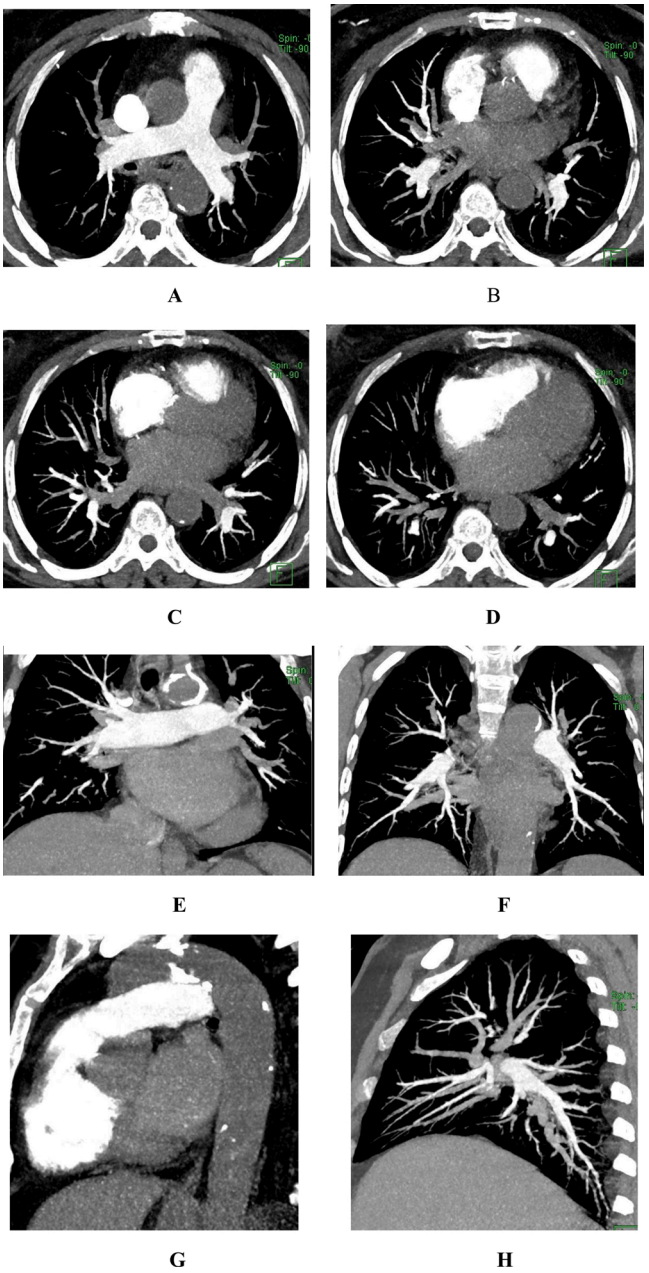


Fig. 3. CTPA with Test bolus method: (A, B, C&D) axial images showing well opacification of the main pulmonary arteries and its branches till the terminal subsegmental branches, clearly seen in coronal images (E&F) and Sagittal images(G&H). In all images there is no contrast opacification of the pulmonary veins, aorta or left side of the heart. According to the scoring chart of interpretation, it has score 4 (Excellent).

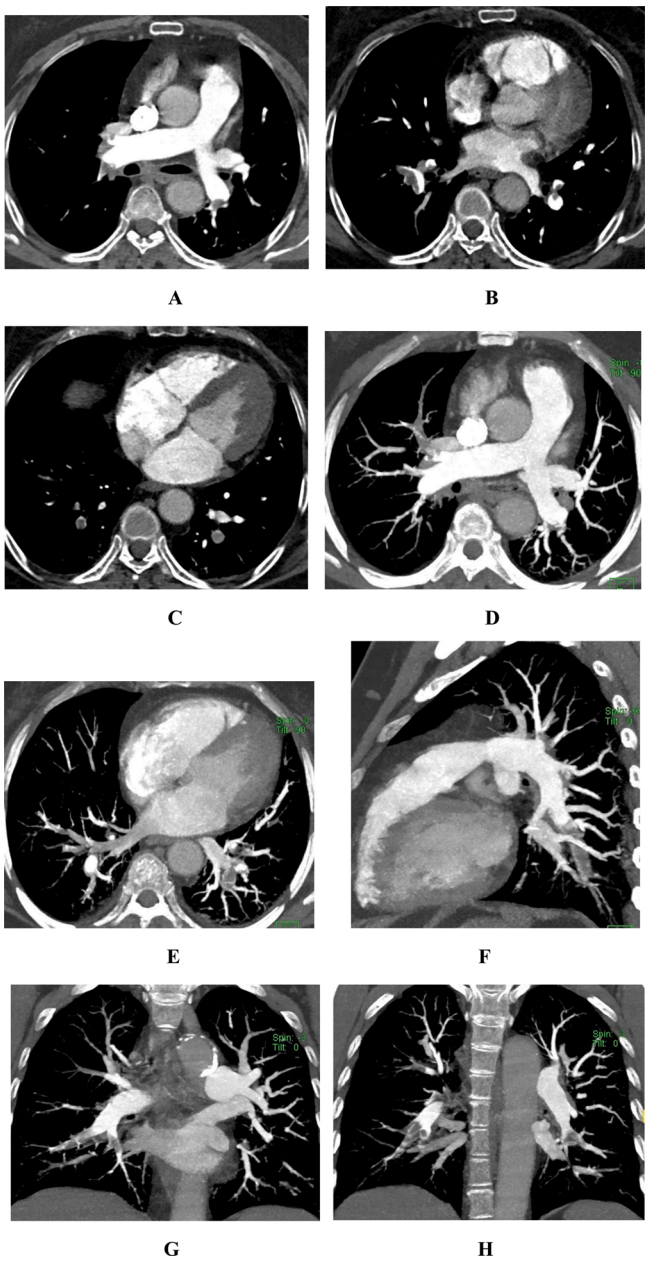


Fig. 4. CTPA with automatic bolus tracking: (A,B&C) axial images (D&E axial MIP), (F) sagittal MIP, (G&H) coronal MIP images showing well opacification of the main pulmonary arteries with bilateral filling defect of PE. All images showing opacification of the pulmonary veins and left side of the heart while the aorta not opacified. Still there is difference in density between the subsegmental branches of pulmonary arteries and pulmonary veins. According to the scoring chart of interpretation, it has score 3 (very good).

Image interpretation was done by two well experienced radiologists (with more than 10 years of experience) independently, blinded to the technique used and the interpretation made by the other radiologist. They reviewed each study for its diagnostic quality as mentioned before based on the selective contrast opacification of the vessels, and corresponding scores assigned in (Table1).

2.5. Statistical analysis

The data collected was analyzed and findings were obtained using

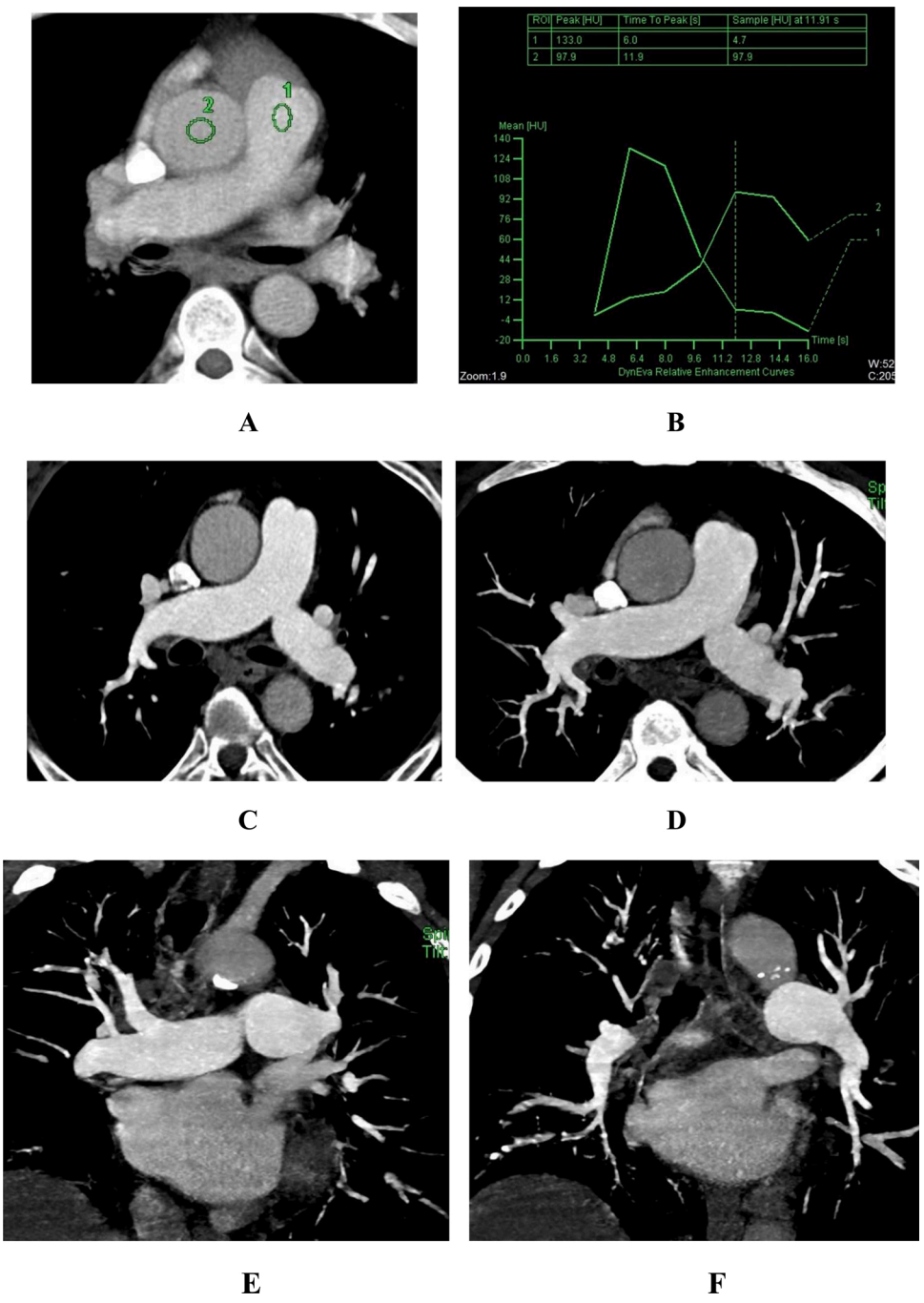


Fig. 5. CTPA with Test bolus method: (A&B) axial images with cursor and dynamic curve showing that the time peak of the pulmonary artery is 6 s and for the ascending aorta is 11.9 s. it is very short time for contrast administration, as the whole examination should be finished before 12 s. In this case the 50 mL of contrast was injected at a rate of 5.5 mL/s with a delay time 2 s. The whole examination finished within 11 s. (C&D) axial images and (E&F) coronal images showing well opacification of the main pulmonary arteries and its branches till the terminal subsegmental branches. However, the pulmonary veins and left side of the heart are seen opacified while the aorta not opacified. Still there is difference in density between the branches of pulmonary arteries and pulmonary veins. According to the scoring chart of interpretation, it has score 3 (Very Good).

the statistical package for social science (SPSS) windows package (version 23, SPSS, Chicago). Descriptive analysis was conducted, including the scoring system, diagnostic score quality, average HU density of the estimated vessels. For all statistical tests, P value of less than 0.05 was considered a statistically significant difference. Cohen's Kappa test was run to determine if there was an agreement between the two radiologists in both groups.

3. Results

- Regarding the results for each technique, 60 % were positive in group A and 65 % were positive in group B (Table 2), however our targeting results were based on the quality of the technique and better enhancement of the pulmonary arteries, subjective and objective assessment.
- According to the score assessment of the study; in group A; 30 % of the cases were satisfactory, 45 % were good, 15 % were very good, 5 % were excellent and 5 % were non diagnostic. While in group B; 5 % of the cases were Satisfactory, 15 % were good, 30 % were very good and 50 % were excellent (details seen in Table 3). There was a good agreement between the two reader's judgments, by using Cohen's Kappa test, $K = 0.9$
- According to contrast density estimation based on Hounsfield units, the main pulmonary artery average density was 260.5 HU in group A and increased to 320 HU in group B with P value < 0.002. On the other hand, the ascending aorta average density decreased from 250 HU in group A to 130 HU in group B with P value < 0.001. Also, the average density of the descending aorta decreased from 220 HU in group A to 95 HU in group B with P value < 0.001. According to the diagnostic quality score of the scans performed by the radiologist,

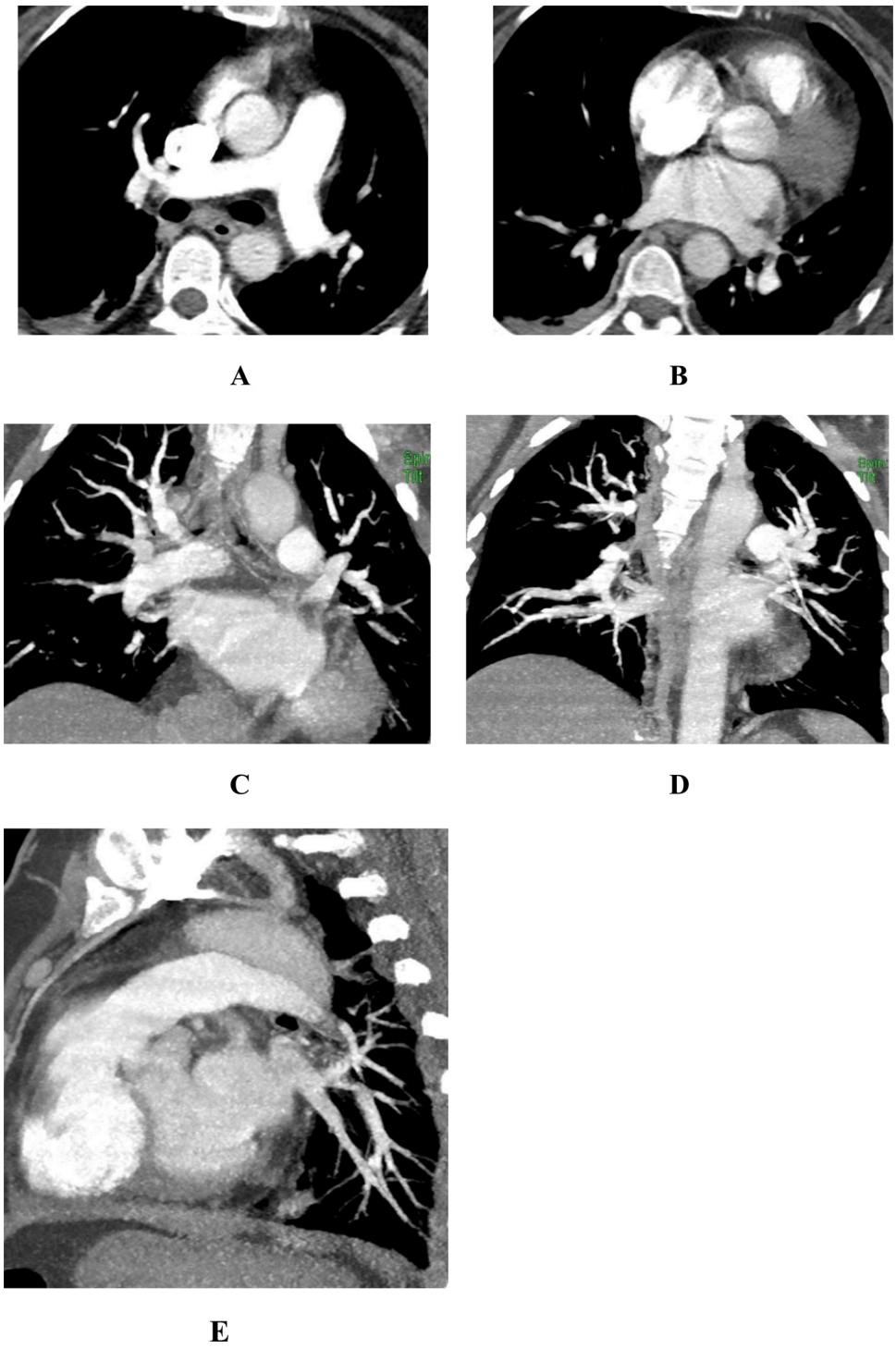


Fig. 6. CTPA with automatic bolus tracking: (A&B) axial images, (D&E) coronal MIP images, (E) sagittal MIP showing well opacification of the main pulmonary arteries as well as the subsegmental branches as seen in sagittal and coronal images. However, the pulmonary veins and left side of the heart as well as the aorta are seen opacified. According to the scoring chart of interpretation, it has score 2 (Good).

the average score was increased by 35 % (from 1.75 in group A to 2.8 in group B with P value $P < 0.001$). (Table 4)

- Regarding the volume of IV contrast needed, it was decreased by 40 % in group B compared to group A.

4. Discussion

Pulmonary embolism as a critical life threating condition must be diagnosed and managed rapidly. MSCTA is the first line and imaging modality of choice in PE diagnosis [6]. MSCT is based mainly on timing of contrast injection and image accusation at the proper time [7]. In our study we provided comparison between the two main techniques of contrast administration and imaging of PE, bolus tracking and test bolus methods.

Many previous comparative studies similar to our study were done like Kavita et al. [1], Godoy et al. [5] and Lorenzo et al. [8] studies. However, in our study we added a step in test bolus technique. We measured the time needed for the contrast to reach the ascending aorta,

Table 1
Scoring chart for radiologist's interpretation of scans.

Type	Score	Details
Non-diagnostic	0	Opacification of pulmonary arteries is poor; the radiologist is unable to diagnose or rule out pulmonary embolism due to poor quality of the scan.
Satisfactory	1	Scan is acceptable for diagnosis, but the pulmonary arteries are not densely opacified; the limited contrast density in the pulmonary vasculature makes diagnosis difficult but not impossible.
Good	2	The pulmonary arteries are well opacified, but contrast is seen in the veins and in the left heart as well. The aorta appears to have the same opacification as the pulmonary arteries; the sub-segmental pulmonary arteries and veins are visible, and a confident diagnosis of filling defect in these also can be made.
Very good	3	The pulmonary arteries are very well opacified, and there is some contrast in the aorta and the left heart; the distal pulmonary arteries are well opacified, and there is some visual distinction between subsegmental pulmonary arteries and veins due to differences in contrast density.
Excellent	4	The pulmonary arteries and their branches to the level of subsegmental branches are very well opacified and clearly identified, and the visual distinction between subsegmental pulmonary arteries and veins is very clear; there is minimal if any contrast spillage in the aorta and the left heart.

Table 2
Positive & negative cases of PE with site distribution of positive cases in both groups.

PE Result	Group A		Group B	
	Reader 1	Reader 2	Reader 1	Reader 2
Positive result	180 (60 %)	179 (59.6 %)	195 (65 %)	196(65.4 %)
Negative result	120 (40 %)	121(40.4 %)	105 (35 %)	104(34.6 %)
PE site of + ve cases				
MPA	11	11	14	14
LPA	43	43	42	42
RPA	48	48	45	45
LPA&RPA	37	37	35	35
Segmental PA	33	34	31	30
Subsegmental PA	8	6	28	30

in addition to the basic step of measuring the time needed for the contrast to reach the pulmonary artery. This step made us able to calculate the exact time needed for contrast injection as the well as estimating the maximum amount of contrast that can be injected and is needed to opacify the pulmonary arteries and the subsegmental branches before contrast reaching the aorta.

Some studies based on optimizing the time delay in automatic bolus tracking technique were trying to improve the quality of the MSCTA examination and obtained images [4,9,10]. However, the variation of cardiac and breathing function of patients were the reasons of not achieving the quality required.

On the other hand, optimization of the time delay on test bolus method is estimated for each patient separately and this leads to contrast concentration and opacification of the main pulmonary arteries and the sub segmental branches [11,12]. Minimal enhancement of veins is considered another advantage of test bolus method that allows better delineation of the arterial system following the bright density of the contrast in the arteries [1]. The step we added in our study, measuring the time needed for contrast to reach the ascending aorta provided a clear vision of these advantages.

In our study, the amount of injected contrast used is much reduced in test bolus technique than in bolus tracing technique depending on the estimated time to reach the pulmonary artery. In addition, the estimated contrast time reaching the aorta gives us the exact time at which the contrast should be injected totally, that should never exceed 15 s in all cases. So in a rate of 6 mm/s and pulmonary time is 9 s, aorta time 15 s, the difference in time 6 s plus 3 s time of image acquisition, the total time is 9 s in a rate of 5.5 m/s the total amount could be used is 49.5 mL. Reduced amount of contrast has a great significance specially in high risk patients, like rising serum creatinine or those on dialysis. Similar studies to reduce volume of contrast were done by Wichmann et al. [13], Szucs et al. [14] and Mathias et al. [15].

In addition, the test bolus technique not only reduces the amount of the contrast but also it increases the quality of the examination by increasing the contrast concentration and opacification of the pulmonary artery and its branches up to the 4th sub segmental branches clearly. Also, following the estimated time curve reduces the artifact from the contrast seen at the SVC, decreases opacification of the pulmonary veins, as well as the left side of the heart and the aorta which gives a clear visualization of the pulmonary artery and its branches. On the other hand, in bolus tracking method almost of the cases have opacification of the pulmonary veins and left sided heart, even if the subsegmental branches of the pulmonary artery visualized, it may be conflicted with the pulmonary veins. Also SVC artifact is more evident in bolus tracking method.

In our study most of the patients were obese and overweight in both groups as seen in Table 5 that force us to use high kv during scanning. In test bolus technique, the amount of contrast was not related to the patient weight, unlike the bolus tracking technique in which we may need

Table 4
Assessment of HU density in targeted vessels in both groups.

	Group A	Group B	P value
Contrast density in HU			
• MPA	260.5 ± 22.5	320 ± 26.4	(P < .002)
• Left PA	240 ± 17.7	305 ± 21.5	(P < .001)
• Right PA	244 ± 16.3	308 ± 21.7	(P < .001)
• A Aorta	250 ± 18.7	130 ± 12.8	(P < .001)
• D Aorta	220 ± 16.3	95 ± 10.5	(P < .001)
Score of diagnostic quality	1.75	2.8	P < .001

Table 3
Scoring of the both groups based on radiologist's interpretation of scans.

Scoring	PA, Segmental, Subsegmental branches	PV	Aorta & Lt heart	Reader 1		Reader 2		Average scoring	
				Group A	Group B	Group A	Group B	A	B
Non-diagnostic (0)	Poor Opacification.	Poor Opacification.	Poor Opacification.	16 (5.4 %)	0%	14 (4.7 %)	0%	5%	0%
Satisfactory (1)	Not densely opacified but acceptable for diagnosis	Not densely opacified	Not densely opacified	89 (29.6 %)	13(4.4 %)	92 (30.6 %)	16(5.4 %)	30 %	5%
Good (2)	Well opacified	Opacified with same density as PA	Opacified with same density as PA	135 (45 %)	43(14.4 %)	132 (44 %)	44(14.6 %)	45 %	15 %
Very good (3)	Very well opacified	Opacified with less density than PA	Opacified with less density than PA	44 (14.6 %)	92 (30.6 %)	47 (15.7 %)	91 (30.4 %)	15 %	30 %
Excellent (4)	Very well opacified & clearly identified	Non opacified	Non opacified	16 (5.4 %)	152 (50.6 %)	15 (5%)	149 (49.6 %)	5%	50 %

to increase the amount of contrast in obese patients [8,16]. However in test bolus even if the amount is increased, it will be of no value as the aorta, the left side of the heart and pulmonary veins will be opacified and degrading the image quality and may interfere with the diagnosis. There was a 5 % non-diagnostic examination in group A related to the weight of the patient and abnormal cardiac function. Similar results were reported by Kavita el al. [1]

On the other hand, by decreasing the timing of the examination, it subsequently decreases the radiation exposure dose of the patient. Many studies were applied for reduction of radiation dose in CTA for PE, depending on the advanced CT technology and dual CT imaging machine [14,17].

The unavoidable limitation of this study was that only one study technique applied for each patient and not both techniques for the same patient, although most patients in both groups had similar patient demographics.

Finally, our comparative study showed that MSCTA using test bolus technique with our added step provided better examination regarding the quality of images, diagnostic performance and reduced volume of contrast used in comparison to MSCTA using automatic bolus tracking method, aim achieved.

5. Conclusion

MSCT-PA using test bolus method reduces the amount of the contrast used, with better opacification of the pulmonary artery and its sub segmental branches in addition to reduced artifact. It is considered to be better than automatic bolus tracking in assessment of pulmonary embolism and we recommend it to be routinely applied in CTA for PE imaging studies with our added step.

Author contributions

Authors are required to identify the contributions for which they are responsible. The author responsible for the integrity of the entire study should be identified. Please list the following phrases and beside each indicate the name(s) of the author(s) to whom they apply:

1. guarantor of integrity of the entire study: Wael H. Kamr, Ahmed I. Tawfik

2. study concepts and design: Wael H. Kamr, Ahmed I. Tawfik, Amir M. El-Tantawy

3. literature research: Wael H. Kamr, Ahmed I. Tawfik, Mohamed M. Harraz

4. clinical studies: Wael H. Kamr, Ahmed I. Tawfik, Amir M. El-Tantawy

5. experimental studies/data analysis: Wael H. Kamr, Ahmed I. Tawfik, Mohamed M. Harraz

6. statistical analysis: Wael H. Kamr, Mohamed M. Harraz, Amir M. El-Tantawy

7. manuscript preparation: Wael H. Kamr, Ahmed I. Tawfik, Mohamed M. Harraz

8. manuscript editing: Wael H. Kamr, Amir M. El-Tantawy

Items that do not apply should also be indicated with N/A. Where there is any uncertainty regarding authorship the editor of the study reserves the right to contact the guarantor of the study for further information.

Table 5
Patient Size Information in both groups.

Patient Size Information	Group A	Group B
Patient Weight		
• <80 kgm	10 (3.3 %)	15 (5%)
• 80–100 kg m	130 (43.4 %)	120 (40 %)
• >100 kg m	160 (53.3 %)	165 (55 %)
Patient Height		
• 150–160 cm	50 (16.6 %)	43 (14.4 %)
• 160–170 cm	165 (55 %)	172 (57.4 %)
• 170–180 cm	70 (23.4 %)	68 (22.6 %)
• >180 cm	15 (5%)	17 (5.6 %)
Body Mass Index (BMI)		
• Healthy weight(18–24.9)	12 (4%)	18 (6%)
• Over weight (25–29.9)	127 (42.4 %)	123 (41 %)
• Obese (30 and above)	161 (53.6 %)	159 (53 %)

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] Kavita P. Dhamanaskar, Kimberly S.E. Figueira, Susan C. Jerome, Brian L. Yemen, Test bolus technique for detection of pulmonary emboli at 64-Slice multidetector computed tomography angiography, Can. Assoc. Radiol. J. 64 (2013) 226–228.
[2] C. Wittram, M.M. Maher, A.J. Yoo, et al., CT angiography of pulmonary embolism: diagnostic criteria and causes of misdiagnosis, Radiographics 24 (2004) 1219e38.
[3] P.D. Stein, S.E. Fowler, L.R. Goodman, et al., Multidetector computed tomography for acute pulmonary embolism, N. Engl. J. Med. 354 (2006) 2317–2327.
[4] C.H. Lee, J.M. Goo, H.J. Lee, et al., Determination of optimal timing window for pulmonary artery MDCT angiography, AJR Am. J. Roentgenol. 188 (2007) 313–317.
[5] M.C. Godoy, et al., Dual-energy MDCT: comparison of pulmonary artery enhancement on dedicated CT pulmonary angiography, routine and low contrast volume studies, Eur. J. Radiol. 79 (2011) e11–7.
[6] Z. Szucs-Farkas, et al., Detection of pulmonary emboli with CT angiography at reduced radiation exposure and contrast material volume: comparison of 80 kVp and 120 kVp protocols in a matched cohort, Invest. Radiol. 44 (2009) 793–799.
[7] J.W. Nance Jr., et al., Optimization of contrast material delivery for dual-energy computed tomography pulmonary angiography in patients with suspected pulmonary embolism, Invest. Radiol. 47 (2012) 78–84.
[8] Lorenzo Faggioni, Emanuele Neri, Paola Sbragia, Rachele Pascale, Luigia D'Errico, Davide Caramella, Carlo Bartolozz, 80-kV pulmonary CT angiography with 40 mL of iodinated contrast material in lean patients: comparison of vascular enhancement with iodixanol (320 mg I/mL)and iomeprol (400 mg I/mL), AJR 199 (2012) 1220–1225.
[9] R. Yuan, et al., Reduced iodine load at CT pulmonary angiography with dual-energy monochromatic imaging: comparison with standard CT pulmonary angiography–a prospective randomized trial, Radiology 262 (2012) 290–297.
[10] M.A. Delesalle, et al., Spectral optimization of chest CT angiography with reduced iodine load: experience in 80 patients evaluated with dual-source, dual-energy CT, Radiology 267 (2013) 256–266.
[11] J. Weiss, et al., Noise-optimized monoenergetic post-processing improves visualization of incidental pulmonary embolism in cancer patients undergoing single-pass dual-energy computed tomography, Radiol. Med. 122 (2017) 280–287.
[12] X. Li, et al., 70-kVp high-pitch computed tomography pulmonary angiography with 40 mL contrast agent: initial experience, Acad. Radiol. 22 (2015) 1562–1570.
[13] J.L. Wichmann, et al., 70 kVp computed tomography pulmonary angiography: potential for reduction of iodine load and radiation dose, J. Thorac. Imaging 30 (2015) 69–76.
[14] Zsolt Szucs-Farkas, Andreas Christe, Boglarka Megyeri, Martin Rohacek, Peter Vock, Endre V. Nagy, Johannes T. Heverhagen, Sebastian T. Schindera, Diagnostic accuracy of computed tomography pulmonary angiography with reduced radiation and contrast material dose: a prospective randomized clinical trial, Invest. Radiol. 49 (4) (2014) 201–208.
[15] Mathias Meyer, Holger Haubenreisser, Christoph Schabel, Christianne Leidecker, Bernhard Schmidt, Stefan O. Schoenberg, Thomas Henzler, CT Pulmonary Angiography in Patients With Acute or Chronic Renal Insufficiency: Evaluation of a Low Dose Contrast Material Protocol, January, 2018.
[16] M.S. Davenport, et al., Contrast material-induced nephrotoxicity and intravenous low-osmolality iodinated contrast material, Radiology 267 (2013) 94–105.
[17] Randy Fanous, Hany Kashani, Laura Jimenez, Grainne Murphy, Narinder S. Paul, Image quality and radiation dose of pulmonary CT angiography performed using 100 and 120 kVp, AJR 199 (2012) 990–996.