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FULL PAPER

Reduced z-axis coverage in multidetector-row CT pulmonary angiography decreases radiation dose and diagnostic accuracy of alternative diseases

¹N MICHALAKIS, MD, ¹C KEYZER, MD, PhD, ²V DE MAERTELAER, PhD, ³D TACK, MD, PhD and ¹P A GEVENOIS, MD, PhD

¹Department of Radiology, Hôpital Erasme, Université libre de Bruxelles, Brussels, Belgium

²Department of Biostatistics and Medical Informatics and Institut de Recherche Interdisciplinaire en Biologie Humaine et Moléculaire, Université libre de Bruxelles, Brussels, Belgium

³Department of Radiology, Epicura Baudour, Baudour, Belgium

Address correspondence to: Dr Denis Tack

E-mail: denis.tack@skynet.be

Objective: To investigate the effect of a two-third reduction of the scanned length (*i.e.* 10 cm) on diagnosis of both pulmonary embolism (PE) and alternative diseases.

Methods: 247 consecutive patients suspected of acute PE had a CT pulmonary angiography (CTPA) of the thorax (standard length, L). Based on this acquisition, a second set of images was created to obtain a scan length of 10 cm caudally to the aortic arch (I). Images were anonymized, randomized and interpreted by two independent readers. The quality of enhancement, the presence of PE and the possible alternative and/or complementary diagnoses were recorded. A McNemar exact test investigated differences in discrepancies between readers and between scan lengths.

Results: 57 (23%) patients had an acute PE. Among I sets, PE was missed by both readers in one (1.8%) patient, because the unique clot was localized in a subsegmental artery out of the 10-cm range. There were discrepancies

between L and I sets in 9 (3.6%) and 11 (4.5%) patients, by Readers 1 and 2 ($p = 0.820$), respectively. Discrepancies between the readers of L sets and those between both sets were not different regardless of the reader ($p > 0.99$). There were discrepancies between both sets for alternative and/or complementary diagnoses in 43 (17.2%) patients.

Conclusion: Although its performance in diagnosing PE is maintained, CTPA should not be restricted to a range of 10 cm centred over the pulmonary hilum, because alternative and/or complementary diagnoses could be missed.

Advances in knowledge: (1) A 10-cm CTPA acquisition reduces the radiation dose by two-thirds as compared with a standard one, but does not impair the accuracy for the diagnosis of PE. (2) Significant alternative diagnoses are missed in 17.2% of patients when reducing the acquisition height to 10 cm.

Acute pulmonary embolism (PE) is a frequently suspected disease. As its clinical presentation is non-specific, imaging is ordered in almost all patients suspected of acute PE.^{1–3} At the beginning of the helical CT era, scanners were too slow to cover the entire thorax length in one breath-hold, using the desired 3 mm collimation. Therefore, only 10 cm centred over the pulmonary hilum was scanned, which allowed CT pulmonary angiography (CTPA) to obtain a diagnostic accuracy >95%.^{4,5} Today, scanning time has been dramatically reduced with the multidetector CT (MDCT) technology, and the entire thorax length is now routinely scanned with an even thinner collimation of ≤ 1 mm. This enables the detection of acute PE in subsegmental and even smaller arteries of the upper and lower lobes. Acquisitions on the entire thorax were also recommended to rule out alternative or

complementary diagnoses,^{6–8} but their usefulness has not yet been proven. The drawback of extending the acquisition length is a higher radiation dose compared with that related to a 10 cm acquisition length. In patients suspected of PE, the radiation dose is of particular concern. The proportion of positive CT examinations ranges currently between 9% and 35% only;^{9–11} patients may be young, particularly females who represent 20% of the patients explored by CT for suspected acute PE, and in whom the mammary glands are highly radiosensitive.¹¹ In these patients, the radiation dose can be reduced while still providing the same level of diagnostic accuracy by reducing the tube current–time product,^{12–14} the tube potential^{13,15} or the distance scanned from 22% to 47%.^{16–18} In these studies, the impact of reducing the scan length of the detection of alternative diagnosis has not yet been investigated.

This study, therefore, aimed to investigate the effect of a two-third reduction of the scanned length (*i.e.* 10 cm) on diagnosis of both PE and alternative diseases.

METHODS AND MATERIALS

Patients

The institutional review board approved the study protocol and waived patient informed consent because our study consisted of interpreting images with no impact on the patient management and no additional radiation dose.

253 consecutive patients who were scanned in our institution for a clinical suspicion of acute PE between September 2010 and July 2012 were prospectively included.

CT pulmonary angiography examinations

CTPA examinations were performed with 16-section or 64-section commercially available MDCT scanners (Sensation 16 and Sensation 64, respectively; Siemens Healthcare, Forchheim, Germany). Patients were examined in the supine position during a single full-inspiration breath-hold with the arms raised behind their head. After a frontal scout view at 100 kVp and 50 mA, a helical CT was performed in the caudocranial direction from the level of the posterior costophrenic angles to the lung apices after injecting 100 ml of a contrast agent containing 400 mg ml⁻¹ iodine (Iomeprol, Iomeron® 400; Bracco, Ferentino, Italy) at the rate of 3 ml s⁻¹ in an antecubital vein via an automated injector (Ulrich Medical®, Ulm, Germany). On the 16-section MDCT scanner, quality effective tube current–time product was set at 90 mAs–eff, tube potential at 100 kVp; with 16 × 0.75 mm collimation. Rotation time was 0.5 s, and pitch was 1.15:1. On the 64-section MDCT scanner, quality effective tube current–time product was set at 120 mAs–eff, tube potential at 100 kVp; with 32 × 0.6 mm collimation, z-flying spot technique. Rotation time was 0.33 s, and pitch was 0.9:1. On both scanners, the automatic exposure control (Care Dose 4D; Siemens Healthcare) was switched on. The injection was administered using an automatic bolus tracking programme, with a region of interest positioned within the pulmonary arterial trunk, and a threshold set at 120 HU. The typical delay for beginning the CT acquisition was 23–25 s.

Images were reconstructed at 0.7- or 0.8-mm intervals, respectively, on the 16- or 64-section scanner using a standard algorithm (B20f), and a field of view adapted to the patient's size with lateral limits on the external cortex of the ribs.

Image analysis

Patient information was erased from all images, and two sets of images were made for each patient—one set with all images obtained on the entire thorax length (L set) and another with images obtained from the bottom of the aortic arch to 10 cm more caudally (I set). Images were randomly numbered by using tables from Fisher and Yates¹⁹ and were loaded on a clinical workstation with three-dimensional functionalities (Wizard™; Siemens Healthcare). The display window setting was set at a centre of –600 HU and a width of 1600 HU for the lungs, and at a centre of 45 HU and a width of 450 HU for the mediastinum, all of which are the routine lung window settings used at our

institution. The readers were free to modify the window settings during their reading at the workstation.

Two independent readers performed image analysis. To eliminate possible memorization of images, we separated readings by at least 2 months. Reader 1 (blinded for review) was a radiologist with 26 years' experience in thoracic CT interpretation and Reader 2 (blinded for review) was a general radiologist with 12 years' experience in reading CT but with no specific training in thoracic imaging. Neither reader was involved in including patients or in conducting the CT examinations. Readers were blinded to all patient identifiers and knew only that the patients were clinically suspected of acute PE.

Readers were asked to score the quality of arterial enhancement (a score of 2 was assigned if the quality was appropriate; 1 if artefacts did not prevent interpretation; or 0 if the examination was not interpretable) and to record filling defects in the pulmonary arteries.

After completing all readings, any discrepancy between the readers on L image sets was solved by consensus. In this study, the standard of reference for the diagnosis of PE consisted of concordant readings on L images or, in case of discrepancy, consensus readings on these sets. In case of discrepancy between both sets by a reader, the reader had to determine whether this discrepancy was due to different scanned ranges or a reading error.

The readers were also asked to code alternative and/or complementary diagnoses as present or absent. The following possible diagnoses were considered: hiatal hernia, pleural effusion, mass, consolidation, diaphragmatic hernia or elevation, atelectasis, pericardial effusion, pulmonary oedema, lymphadenopathy, aortic dissection and pneumothorax. Among these alternative and/or complementary diagnoses, mass(es), consolidation, atelectasis, aortic dissection and pneumothorax were considered clinically relevant, as they could impact the immediate clinical management. In case of discrepancy between both sets by a single reader, the reader had to confirm that this discrepancy was actually due to differences in scanned ranges.

To cross-check if clinically relevant alternative and/or complementary diagnoses missed on the I set could be seen on the scout view, the most experienced reader was also asked to interpret the scout views to determine whether it could be possible to detect them and thus decide to acquire L instead of I set images.

Radiation dose

Dose descriptors displayed on the CT dose report were recorded. This included CT dose index volume (CTDIvol) and the dose–length product (DLP) that corresponded to the L acquisition. We assumed that the CTDIvol of an I acquisition would be similar to that of the L acquisition. Therefore, we calculated the DLP of I acquisition by multiplying the CTDIvol of L acquisition provided by the dose report by 10 cm. We thus ignored the additional dose reduction that would have been obtained by the dose modulation system in the mid-lung zones, which required lower tube currents than the lung bases and apices. Finally, we calculated the effective

dose of the examination for L and I by multiplying the DLP by $0.017 \text{ mSv mGy}^{-1} \text{ cm}^{-1}$.^{20,21}

Statistical methods

Because a definite diagnosis from an independent method of reference cannot be obtained and because L set of images is not an *a priori* gold standard, our study compared discrepancies among readers and among sets.

McNemar and Fisher exact tests of comparisons were performed to look for the possible differences between proportions of discrepancies. A possible effect of age, origin of referral or final PE diagnosis on the probability of discrepancies was tested using a logistic binary regression. Statistical significance was set at $p < 0.05$. Statistical analyses were performed with the use of the IBM® SPSS® software Windows™ v. 19.0 (SPSS Inc., Chicago, IL).

RESULTS

On the L sets, Reader 1 scored the quality of the arterial enhancement as 0, 1 or 2, in 1 (0.4%), 36 (14.2%) and 216 (85.4%) patients, respectively. For the same aspect, Reader 2 scored 0, 1 or 2 in 6 (2.4%), 50 (19.8%) and 197 (77.9%) patients, respectively. Six patients were excluded from our study group since they received an arterial enhancement score of 0 by at least one reader. This study was thus based on 247 patients [124 females, 123 males; mean age, 64 years $\pm$ 17 (standard deviation); range, 19–95 years]. Among these 247 patients, 140 were referred by the emergency room and 107 by various other departments of our hospital. 56 patients were scanned on the 16-section scanner and 191 on the 64-section scanner.

On the L sets, PE was detected in 49 and 59 patients by Readers 1 and 2, respectively, but there was disagreement in 10 patients. Reviewing the discrepancies in these 10 patients by consensus, it appeared that Reader 1 had missed PE in 8 (14.0%) patients, whereas Reader 2 erroneously diagnosed PE in 2 (3.5%) patients.

A final diagnosis of PE was therefore made in 57 (23.4%) patients in our study.

Regarding the I sets, PE was detected in 50 and 58 patients, by Readers 1 and 2, respectively. Among the 57 patients with a final diagnosis of PE, Readers 1 and 2 missed this diagnosis in 10 (17.5%) and 5 (8.8%) patients, respectively. PE was missed by both readers in one (1.8%) patient because the unique clot was localized in a subsegmental artery located out of the scanned range. In nine and four other patients, where the filling defects were within the scanned range, Readers 1 and 2, respectively, missed the diagnosis.

Among the 247 total patients, there were discrepancies for the diagnosis of PE between L and I sets in 9 (3.6%) and 11 (4.5%) patients, by Readers 1 and 2, respectively. The proportion of discrepancies (9/247 vs 11/247) was not statistically significantly different between the readers ($p = 0.820$).

The proportion of discrepancies between readers on L sets and the proportion of discrepancies between the sets by each reader were then compared (8/247 vs 7/247 for Reader 1 and 6/247 vs 7/247 for Reader 2). These proportions were also not statistically significantly different ($p > 0.99$ for each comparison), suggesting that discrepancies between sets were not more frequent than between readers.

The frequencies of alternative and/or complementary diagnoses proposed by each reader on each set are listed in Table 1. The proportions of alternative and/or complementary diagnoses missed on the I set as compared with the L set are listed in Table 2. Discrepancies between the I and L sets for clinically relevant alternative and/or complementary diagnoses were observed in 12 (4.9%) patients. Discrepancies between the I and L sets for clinically irrelevant alternative and/or complementary diagnoses were observed in 31 (12.5%) patients. There was no discrepancy

Table 1. Frequency of alternative and/or complementary diagnoses on each image set by each reader

Alternative and/or complementary diagnosis	L Set		I Set	
	Reader 1	Reader 2	Reader 1	Reader 2
Hiatal hernia	10	28	6	6
Pleural effusion	99	109	97	102
Mass(es)	14	18	13	15
Consolidation	61	48	56	43
Diaphragmatic hernia or elevation	18	10	15	7
Atelectasis	25	26	24	23
Pericardial effusion	14	21	13	19
Pulmonary oedema	14	13	14	11
Lymphadenopathy	29	63	29	61
Aortic dissection	1	3	1	3
Pneumothorax	1	2	1	2

I set, set with images obtained from the bottom of the aortic arch to 10 cm more caudally; L set, set with all images obtained on the entire thorax length.

between the I and L sets for alternative and/or complementary diagnoses in 204 (82.6%) patients. The probability of discrepancy for clinically relevant alternative and/or complementary diagnoses between the I and L sets and the probability of no discrepancy or clinically irrelevant alternative and/or complementary diagnoses were not influenced by the age of the patients ($p = 0.178$), referral by the emergency room or by other departments of the hospital ($p = 0.103$) and the final diagnosis of PE ($p = 0.218$).

Observing that the I set did not enable to detect clinically relevant alternative and/or complementary diagnoses, the most experienced reader reviewed the scout views and determined whether the anomaly could be seen on this view and could thus require an L set instead of I set. Table 2 shows the proportions of alternative and/or complementary diagnoses undetected on the scout view among the examinations on which an alternative and/or complementary diagnosis had been missed.

The mean scanned length on L sets was 296 ± 80 mm. For L sets, mean DLP and mean CTDIvol were 167.3 ± 15.6 mGy cm and 5.2 ± 0.7 mGy, respectively. Mean DLP for I sets with a 10-cm coverage in the z-axis was 52.0 ± 7.0 mGy cm. The dose reduction of I was 69% when compared with L. The effective dose of L was 2.8 ± 0.3 mSv and of I was 0.9 ± 0.1 mSv.

DISCUSSION

The results of our study suggest that (1) reducing the scanned range to 10 cm centred over the pulmonary hilum does not impair the performance of CTPA in diagnosing acute PE, (2) relevant alternative and/or complementary diagnoses are missed by this reduced range and (3) the radiation dose reduction

through a 10-cm acquisition approximates two-thirds of that delivered by standard length.

Three previous studies have reduced the scanned length by 22%, 37% and 47% and have shown that such reductions do not impair the diagnosis of acute PE.^{16–18} In our study, z-axis coverage was reduced to approximately one-third (100 mm compared with 296 ± 80 mm) and only 1 of the 247 patients with a segmental PE was misclassified, because his unique clot was localized out of the scanned range. Reduced z-axis coverage could of course miss PE in the segmental or even more distal arteries in the lung apices and lung bases. Nevertheless, the clinical relevance of these PEs is still a matter of debate. Studies that have evaluated the prognosis of patients who received falsely negative helical CT scan centred on their pulmonary hilum have shown that such scans are sufficient to exclude PEs that are clinically important to treat.^{4,5,22} In addition, the prognosis of patients who have untreated sub-segmental PE but who do not have cardiorespiratory-associated disease is not different than that of those without PE.²³

In our study, the comparison of proportions shows that discrepancies between the L and I sets interpreted by the same reader are not statistically different from discrepancies between readers on L sets. Discrepancies between scanned lengths are not more frequent than those between readers—in other words, reducing scan length does not induce wider variability than changing readers. Therefore, considering the diagnosis of PE alone, it seems clinically reasonable to propose reducing the scanned length to 10 cm and consequently the radiation dose. This proposal is in accordance with the findings reported by Litmanovich *et al*,²⁴ who showed that in pregnant females, reducing z-axis coverage results in a substantial reduction of radiation dose while maintaining diagnostic image quality for PE. However, they did not investigate the impact of this reduction on the alternative diagnoses.

Detecting alternative and/or complementary diagnosis is important, and several studies have revealed that such alternative diagnosis was discovered by using helical CT in approximately two-thirds of patients suspected of acute PE. Nevertheless, Hull⁸ and others^{25–28} have shown that among these two-thirds, less than one required specific and immediate intervention. Our study also shows that reducing the scanned range to 10 cm could indeed result in missed alternative and/or complementary diagnoses in proportions ranging from 0% to 80%, depending on the considered diagnosis. The first most frequently missed complementary diagnosis was *hiatal hernia* (approximately 80%). This could be easily explained by the inferior location of hiatal hernia in the thorax, but this complementary diagnosis is by far not clinically relevant in most of the cases. The second most frequently missed complementary diagnosis was *mass* (approximately 25%), which could impact on the clinical management, especially if the current CTPA is the only scan obtained in the patient. Kino *et al*²⁹ detected a previously undiagnosed lung cancer in only 0.45% of patients, where acute PE was suspected and who were referred from the emergency room. In our study, other alternative or complementary diagnoses were missed in 5–10% of cases depending on the considered clinical relevance and reader. Among them, consolidation—missed in approximately 12% of cases—is probably the

Table 2. Proportions of alternative and/or complementary diagnoses missed on I set as compared to L set and undetected on scout view by the most experienced reader

Alternative and/or complementary diagnoses	Missed on I set	Undetected on scout view
Hiatal hernia	21/27	17/21
Pleural effusion	5/69	2/5
Mass(es)	6/25	6/6
Consolidation	6/68	2/6
Diaphragmatic hernia or elevation	3/19	0/3
Atelectasis	2/38	2/2
Pericardial effusion	2/21	2/2
Pulmonary oedema	2/20	2/2
Lymphadenopathy	1/54	1/1
Aortic dissection	0/1	0
Pneumothorax	0/1	0

I set, set with images obtained from the bottom of the aortic arch to 10 cm more caudally; L set, set with all images obtained on the entire thorax length.

most clinically relevant, as it can explain the symptoms of patients suspected of acute PE and for which specific and effective treatment can be given. Richman et al³⁰ reported that pneumonia was the most frequent diagnosis among those considered as life threatening; requiring specific and immediate intervention. Interestingly, we could not elicit any criteria (patients' age, referral from the emergency room or from other departments of the hospital or the final diagnosis of PE) that could suggest restricting the scan range to 10 cm or increase the range to >10 cm. The scout view also did not affect this decision, as it did not pick up abnormalities beyond the 10 cm range, which would have led us to lengthen the range to include that abnormality.

In patients where PE is suspected, the effective dose delivered by MDCT protocols ranges from 2 to 6 mSv.¹ There are also reports of even higher dose exposure. Hurwitz et al³¹ recently reported that the effective dose delivered by 64-detector-row MDCT ranges from 12 to 32 mSv. In terms of radiation dose, restricting the scanned range to 10 cm in addition to using optimized CT parameters allows reducing the dose by approximately one-third with mean DLP at 52 mGycm, which corresponds to a sub-millisievert examination (0.9 mSv).

Our study has limitations. First, this study suggests that there is no statistical difference in performances between scanning 10 cm over the pulmonary hilum and the whole chest. However, the fact that we did not detect any difference does not mean that no difference exists, which could be detected with a higher sample size. Consequently, our findings, including the possible appropriateness of the scout view for selecting the acquisition length, should be considered as preliminary and need to be confirmed by studies with larger cohorts. Second, we did not investigate whether missed alternative

and/or complementary diagnoses were previously known or detectable with more easily performed or less radiating methods, such as chest radiographs. Additionally, we did not investigate the impact of the alternative and/or complementary diagnoses on patient management. Third, we have not considered any pre-test clinical probability through scores such as the Geneva score or the Well's score. Indeed, restricting the scan range to 10 cm could be suggested if the clinical probability is high. Fourth, we did not record the body weight and/or body mass index of the patients. Applying our CT protocols in an obese population might have induced higher DLP than those observed in this study. Finally, we assumed that the CTDIvol in the mid-lung zones would be equal to that obtained in the entire chest. By assuming this, we overestimated the DLP of the 10-cm acquisition. It is, however, to note that conversion factors for estimating effective dose from DLP applied to the entire chest are not appropriate when limiting the scan range to the mid-lung zones. Indeed, this zone includes the breasts and is, therefore, highly sensitive to radiations.³² The appropriate conversion factor could be as high as 0.032 mSv mGy⁻¹ cm⁻¹ and not the default one of 0.017 mSv mGy⁻¹ cm⁻¹.^{20,21,32} Thus, risk estimates based on DLP and/or on conversion factors suited for the entire chest overestimate the dose reduction of I sets as compared with L sets.

Unlike reducing the dose by limiting the z-axis coverage, newest technologies and, in particular, iterative reconstruction techniques and newest detectors will enable radiation dose reduction without impairing the detection of alternative diseases.

In conclusion, although its performance in diagnosing PE is maintained, CTPA should not be restricted to a range of 10 cm centred over the pulmonary hilum because alternative and/or complementary diagnoses could be missed.

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