Articles

Paddlewheel multi-slice helical computed tomography reformation in the detection of pulmonary embolism

An initial experience

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ABSTRACT

الأهداف: تقييم التصوير بالأشعة المقطعية مع تشكيل الصور باستخدام طريقة العجلة في تشخيص الجلطات الرئوية.

الطريقة: أجريت الدراسة على المرضى المشتبه اصابتهم بجلطات رئوية وذلك خلال الفترة من ديسمبر 2011م الى فبراير 2013م بقسم الأشعة، مستشفى دلة، الرياض، المملكة العربية السعودية حيث تم إجراء الأشعة المقطعية للمرضى ثم إعادة تشكيل الصور على طريقة العجلة على أن يكون المركز في تفرع الشريان الرئوي الرئيسي وذلك على زوايا مختلفة ودرجة سماكة مختلفة للشرائح.

النتائج: من بين 71 حالة (44 أنثى، 27 ذكر) مشتبه باصابتهم بجلطات رئوية من حالات الدراسة 43 حالة كانت موجبة للجلطات الرئوية في حين 28 حالة كانت سالبة، تراوحت أعمار المرضى من 99-15 عام. وقد وجد أن الطريقة المستخدمة في الدراسة ذات دلالة احصائية في تشخيص الجلطات الرئوية.

خاتمة: استخدام طريقة العجلة في تشكيل الصور بزاوية دوران أقل وسماكة أقل للشرائح يزيد كفاءة الأشعة المقطعية في تشخيص الجلطات الرئوية.

Objectives: To assess the value of paddlewheel multi-slice helical CT techniques in the detection of pulmonary embolism (PE).

Methods: A prospective study was conducted from December 2011 to February 2013 at the Radiology Department, Dallah Hospital, Riyadh, Kingdom of Saudi Arabia. The CT scans of 71 patients presented for CT pulmonary angiography were selected and interpreted by 2 radiologists using reformatted paddlewheel technique besides coronal multiplanar volume reconstruction (MPVR). Paddlewheel reconstruction was carried out using inbuilt software on sagittal and axial images, setting 5 and 2 mm slab thickness with 5 and 2 degree angle rotation. Reference standard was overall interpretation of coronal MPVR and paddlewheel reformatted images by both radiologists.

Results: In 71 patients (44 were females and 27 were male) with suspected PE, 43 were found to be positive, and 28 were found to be negative. The youngest patient was 15 years old, and the oldest was 99 years of age. Paddlewheel reformatted images display significantly high sensitivity and specificity in eliciting total number of pulmonary emboli compared to coronal MPVR by detecting 51 additional emboli. Decreasing slab thickness and rotation angle enhanced sensitivity of paddlewheel reformatted images by detecting another 11 emboli.

Conclusion: The paddlewheel CT angiography technique with fine slice thickness and less rotational angle enhances PE imaging.

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Pulmonary embolism (PE) is considered a major cause of morbidity and mortality.[1,2] Mortality often occurs due to missed diagnosis; the reason being its multiple non-specific manifestations.[3] Spiral computed tomographic pulmonary angiography (CTPA) has been used in the evaluation of patients with clinically suspected PE for decades.[4,5] Rapid scanning decreased motion artifacts with enhanced evaluation of vessels on one hand, whereas on other hand, thinner collimation increased the work load by increasing the images for review.[6] Although CT is the first line of investigation for diagnosing emboli, however, its limitation for detecting peripheral emboli is still an obstacle in labeling it as a sole reference standard for imaging PE.[4-7] A new image display method uses a set of planar slabs arranged in a paddlewheel, or rotational pattern with pivot on a central horizontal axis between the lung hila, thus providing an uninterrupted depiction of branching vessels radiating from the hila.[8,9] Acquiring CT images through this method unfolds a new facet of imaging pulmonary vasculature, however, optimal parameters for data acquisition are still under research.[8] In this study, we aim to assess the value of paddlewheel multi-slice helical CT reformatted images to detect PE, and to further compare the effect of different slab thickness and rotation angles used for reconstruction.

Methods. This prospective study included 71 adult subjects with suspicion of PE presenting to the Radiology Department of Dallah Hospital, Riyadh, Kingdom of Saudi Arabia from December 2011 to February 2013. All cases with clinical suspicion of PE attending the Radiology Department referred from the Emergency Department or inpatient for CT chest study to diagnose PE were included. Exclusion criteria includes pregnant women and patients with history of renal failure, in which intravenous contrast injection is contraindicated. Human ethics committee approval for this study was obtained from the institutional review board of Dallah Hospital. All CT scans were performed using CT scanner (Light Speed TM 7.X CT scanner, GE Medical systems, Cleveland, USA). Gantry position rotation period was 0.4 seconds, with an x-ray tube voltage of 140 Kv, and a current of 230-350 mA. Cranio-caudal image acquisition of the entire thorax was carried out with a collimation of 1.25 mm (pitch 6), and a reconstruction increment of 0.8 mm. Mean scan time was 2.30 seconds. All patients underwent CTPA after the administration of 100 ml standard contrast media (Xenetix 350 mg/ml, Guerbet, France) with an injection rate of 4.5-5 ml/s via 16 gauge catheter inserted into ante-cubital vein. Contrast bolus was followed by a 10 ml saline flush using Enhanced Xtream injector (Nemoto Dual Shot Alpha (CiA425 Class IV/ GE), and delay was estimated using semiautomatic bolus tracking system (SmartPrep, GE Medical system, Cleveland, USA) with a threshold of 80 HU for all examination. The region of interest (ROI) for bolus tracking was measured in the right atrium. All images were stored and sent to the workstation (VEPRO, AG, Germany).

The CT reformations. All reformations were performed by a senior CT technologist. From the axial CT data sets, multiplanar volume reconstruction (MPVR) maximum intensity projection images were reformatted in both rotational paddlewheel planes. Main pulmonary artery is taken as central axis, thus images acquired are an uninterrupted display of pulmonary vasculature radiating from the hila. For each patient, 3 sets of paddlewheel images were generated. First, 2 reformations were carried out in sagittal scout image with 5 and 2 mm slab thickness. The angle between successive slabs was 5 and 2 degrees with whole rotation coverage of 180 degrees. With this technique, a total of 36-90 images covered the whole lung. The third reformation was carried out in axial scout image with 2 mm slab thickness and 2 degree rotation angle.

Image review. All axial and reformatted images were reviewed with a standard mediastinal window settings (window width, 400 HU; window level, 40 HU) on a picture archiving and communication system workstation (VEPRO, AG, Germany). Blind and random analysis was carried out for evidence of PE on a per-vessel basis with the final consensus of 2 readers. To avoid any potential bias, an intentional 2-weeks interval was created between the 2 readings. Pulmonary embolism was defined as a partial or complete intra-luminal filling defect surrounded by contrast medium and occupying entire arterial vessel section.[10] The central, lobar, segmental, and sub-segmental vessels of each lung were assessed for evidence of PE. The main pulmonary artery, left, and right pulmonary arteries and interlobar arteries were considered as central vessel.[11] Presence or absence of emboli in the pulmonary artery or its branches was carried out using a nomenclature outlined by Remy-Jardin and Remy,[10] which is based on the standard descriptions by Boyden.[12] A 4-point scale was formulated to score different anatomical levels of pulmonary arteries of each lobe: 1 - central (main, right, left, and interlobar); 2 - lobar; 3 - segmental; and 4 - sub-segmental levels. We calculated the percentage of overall detection of PE for paddlewheel and coronal MPVR methods, and with different slab thickness and degree of rotation angles. For each patient, the total number of emboli detected at each pulmonary artery level was determined with the aggregate number of emboli identified on the coronal MPVR and paddlewheel reformatted data sets. That number was used as the denominator for calculation of percentages of overall detection of PE at each pulmonary artery level for other data sets. It was ensured that no embolus was recounted for each patient by numbering each clot according to its specific location. Finally, paddlewheel reformation in axial scout image was carried out, for which central axis was at the main pulmonary artery bifurcation using a 2 degree rotation angle and 2 mm slab thickness. Reference standard was the final consensus of overall interpretation of coronal MPVR and paddlewheel reformatted scans by both radiologists.

Statistical analysis was performed using Statistical Package for Social Sciences version 17 (SPSS Inc, Chicago, IL, USA). Overall sensitivity and specificity of paddlewheel reformatted CT images was calculated. Moreover, its sensitivity and specificity was also calculated regarding the anatomical level of emboli at the same and different slab thickness and rotation angles. The linear, weighted *k* statistic was applied for inter-observer agreement between the 2 radiologists. The *k* value range from -1 (no agreement) to 1 (almost perfect agreement). Agreement was rated poor (k<0.00), slight (0.00-0.20), fair (0.21-0.40), moderate (0.1-0.60), substantial (0.61-0.80), or almost perfect (>0.81).[12] Chi-square test was used and p<0.05 were considered statistically significant.

Results. In 71 patients (44 females and 27 males) with suspected PE, 43 were positive, and 28 were negative. The youngest patient was 15 years old, and the oldest was 99 years old. After integration of all data from coronal MPVR and paddlewheel reformation in positive cases of PE, a total of 92 emboli were detected. These included 36 emboli at central, 29 at lobar, 21 at segmental, and 6 emboli at sub-segmental levels. All 6 emboli at sub-segmental levels were identified on paddlewheel reformation with none elicited on coronal MPVR (**Table 1**). Ninety-two clots were detected by the first radiologist on paddlewheel reformatted images, however, there were 41 clots on coronal MPVR. The second radiologist read 89 emboli on paddlewheel reformatted images, and 36 clots on coronal MPVR. None of the radiologist could elicit sub-segmental emboli on coronal MPVR images (**Table 1**). The percentage of positive cases of PE keeping slab thickness and degree of angle rotation unchanged, significantly increased on paddlewheel reformation. The percentage of positive cases on coronal MPVR images was 32.3% (23 of 71), which increased significantly on paddlewheel reformation to 60.5% (43 of 98). Sensitivity was 44.1% and specificity was 50% for pulmonary emboli on coronal MPVR, and on paddlewheel reformatted images, the sensitivity was 82.6%, and specificity was 85.7%. The percentage of detection of emboli for paddlewheel technique enhanced by decreasing slab thickness from 5-2 mm, and degree of rotation from 5-2 degrees. An additional 11 emboli were detected when slab thickness and degree of angle rotation was decreased to 2 mm and 2 degrees, thus increasing sensitivity on paddlewheel technique to 79.4% compared to 75% sensitivity with 5 mm slab thickness and 5 degree rotation. Paddlewheel reformation with data acquisition on axial scout elicited 3 additional emboli at segmental level in comparison to paddlewheel reformation with data acquisition on sagittal scout. All 92 emboli were detected by the first radiologist, however, the second radiologist detected 89 emboli (**Table 2**). The inter-observer agreement of overall detection of PE on paddlewheel reformatted images is 0.733, which is substantial. Paddlewheel reformation had statistically significant percentage of overall detection of PE than coronal MPVR with equal slab thickness with a p<0.001.

Discussion. We tried to assess the potential status of paddlewheel reformation in currently available

Table 1 - Total number of emboli detected by coronal multiplanar volume reconstruction and all paddlewheel reformations in subjects included in a study conducted at Dallah Hospital, Riyadh, Kingdom of Saudi Arabia (n=92).

Radiologists	Coronal reformations				Paddlewheel reformations			
	Central	Lobar	Segmental	Sub-segmental	Central	Lobar	Segmental	Sub-segmental
First	23	15	3	0	36	29	21	6
Second	22	13	1	0	36	29	21	3

Table 2 - Total number of emboli detected by paddlewheel reformations by both radiologists in subjects included in a study conducted at Dallah Hospital, Riyadh, Kingdom of Saudi Arabia (n=92).

Slab thickness		Radiologist 1				Radiologist 2			
	Degree of rotation	Central	Lobar	Segmental	Sub-segmental	Central	Lobar	Segmental	Sub-segmental
5 mm	5 degrees	34	29	14	4	34	29	14	4
2 mm	2 degrees	36	29	21	6	36	29	21	3

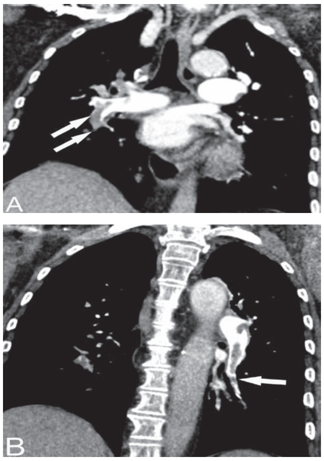

Figure 1 - Coronal multiplanar volume reconstruction in a 75-year-old female patient with acute chest pain displaying thrombus at: **A**) right pulmonary artery (double arrows), and **B**) left pulmonary artery with inferior segmental artery extension (arrow).

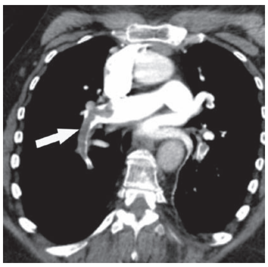

Figure 2 - Paddlewheel image (5 mm slab thickness/5 degree rotation angle) shows the full extent of embolism (arrow) with extension to the segmental and sub-segmental branches. These images result in an increase in connectivity of vessels compared to the coronal display.

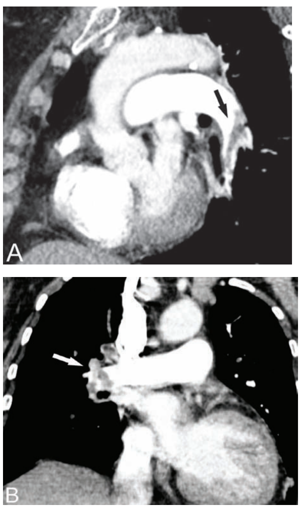

Figure 3 - Paddlewheel reformation (2 mm slab thickness/ 2 degree rotation angle) using axial scout image, improving assessment of embolus with separate visualization of: **A**) left, and **B**) right pulmonary arteries.

long list of diagnostic modalities for detection of PE. Technically, the paddlewheel method was easily implemented on our CT scanner (Light Speed TM 7.X CT scanner, GE Medical systems, Cleveland, USA). Image reconstruction protocol was simple and easily learned by our technologists, already familiar with standard CT reconstruction methods. In our experience, the protocol was not time consuming, and took only a few minutes to perform. We utilized the primary advantage of the paddlewheel display, in which individual slab reconstructions were anatomically more easier to interpret. Branching structures were displayed in continuity from the hilum to pleura, thus smaller arteries and veins were readily recognized by their connection to their respective larger central vessels. Based on the same fact, one can differentiate a small lung nodule from the adjacent vessel or bronchus.

The first goal of our study was to compare the sensitivity and specificity of paddlewheel technique in evaluation of PE compared to coronal MPVR. Paddlewheel method was significantly superior to the coronal MPVR. The basis of increased sensitivity of the paddlewheel technique was continuous display of vessels compared to coronal MPVR, which has more fragmented exhibition of vessels. Keeping this principle as basis, we tried to assess whether paddlewheel reformatted images will depict additional relative to coronal MPVR. In this regard, there were 51 additional emboli depicted with the paddlewheel method. Thus, paddlewheel method offered potential advantages in its uninterrupted display of branching vessels from the hila to the lung periphery, thus improved diagnostic efficiency in our study (**Figure 1**).

Our second goal was to compare different slab thicknesses and rotation angle used in rotation paddlewheel method for visualization of PE to justify its inclusion as a new reformation in the standard protocol in our department. Multiple studies have shown that the thinner the collimation, the better the depiction of the smaller peripheral arteries.[13,14] We tried to optimize visualization of smaller peripheral arteries, with performing the study at the thinnest slice thickness (2 mm). We found that a percentage of overall detection of PE increased with decreasing slab thickness for paddlewheel from 5-2 mm for segmental and sub-segmental arteries (**Figure 2**). An additional 11 emboli were detected when the slab thickness and degree of angle rotation were decreased to 2 mm and 2 degrees, thus increasing sensitivity on paddlewheel technique. Chiang et al[11] advocated the significance of decreasing slab thickness in order to increase the visualization of emboli. In another study, Schoepf et al[14] has emphasized the role of 1 mm collimation to detect sub-segmental emboli. Decreasing the slab thickness where on one hand increased the sensitivity of overall detection of emboli, on the other hand, increased the total number of images to be reviewed, which was considered as a demerit. In our study, the number of images increased from 36-90 by decreasing slab thickness from 5-2 mm.

Axial CT pulmonary angiographic images are considered highly sensitive and specific for detecting pulmonary embolism, however, we tried to exploit the fact that pulmonary vessels do not run in axial plane rather course obliquely to axial plane. Thus, the reformatted images would be better in assessing the vessel in continuity. Not only the images were useful in detecting total number of emboli but also display the cranio-caudal extent of the embolus, which could easily be used to calculate the embolic burden. Besides paddlewheel reformation in sagittal scout, we tried to experiment reformation by using axial scout, which finally provided us another distinctive display of pulmonary vasculature. The images parted the right and left arteries with a complete demonstration of arteries from origin to termination (**Figure 3**). In our study, we found that paddlewheel reformation on axial scout images did not result in improved accuracy compared with reformation on sagittal scout at central or lobar pulmonary levels, however it did display more emboli at segmental levels. We considered this method as an initial experiment, which requires further detailed evaluation and research. Despite the distinguishing presentation of pulmonary vessels, it cannot be included in the routine protocol of our department at this stage. However, based on this pioneer study, we would be able to explore exclusive strengths of this reformatting method in future studies.

Our study had certain limitations. To start with the most important, we did not include conventional pulmonary angiography as a gold standard. In our hospital, the procedure is rarely performed, and we could not use it as a reference. We kept the final consensus of the 2 radiologists on paddlewheel reformatted images as a standard. Overall, we tried to assess the percentage of positive cases detected by coronal MPVR and paddlewheel reformatted images. Secondly, our study was carried out on small sample volume (n=71), which lowers the statistical significance of the study. However, including discretely obvious cases of PE did help in compensating results statistically. The selection criteria of patients provided us ideal cases, which had excellent image quality with no associated lung parenchymal changes or pleural abnormalities. We tried to make sure best contrast opacification of pulmonary vessels with least possible artifacts that helped us to compare different methods of viewing image data sets to its maximum.

In conclusion, results from our study show that paddlewheel CTA technique with fine slice thickness and less rotational angle enhances PE imaging. It provides a continuous rather than a fragmented display of vessels, thus improving the diagnostic efficiency. In future studies, we aim to institute the paddlewheel reformation with all multi-detector CT pulmonary angiographic studies, and to review them in conjunction with the axial images.

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