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ORIGINAL ARTICLE

Computer-assisted Diagnosis of Pulmonary Embolism in Multidetector Computed Tomography

M Zimmermann, M Das, CK Kuhl, S Keil

Department of Diagnostic and Interventional Radiology, RWTH Aachen University Hospital, Aachen, Germany

ABSTRACT

Objective: *To assess the performance of a computer-assisted diagnosis (CAD) software in detecting pulmonary embolism (PE) on multidetector computed tomography (MDCT).*

Methods: *MDCT angiography data of 100 consecutive patients with clinically suspected PE were retrieved. Diagnosis (initial read) had been made in consensus by two out of 10 radiologists. The original data were transferred to a CAD software, and two other experienced chest radiologists reviewed all CAD markings to determine the ground truth for CAD and the standard of reference (final diagnosis) in consensus. The markings were categorised as true or false positive. For true positive, the involved vessel segment was classified as lobar, segmental, and subsegmental. Sensitivity, specificity, and negative and positive predictive values of initial and CAD diagnoses were compared.*

Results: *In the initial read, 27 and 73 patients were positive and negative for PE, respectively. Based on the standard of reference, five (6.9%) of the 73 patients negative for PE were determined to be false negative and the remaining 68 were true negative. The CAD software marked 86 and 14 patients with and without pulmonary emboli, respectively. Based on the standard of reference, 26 were true positive, 57 were false positive, 11 were true negative, and 6 were false negative. The CAD software detected pulmonary emboli in five (6.9%) of 73 patients who were initially read as negative, but failed to detect pulmonary emboli in six (22.2%) of 27 patients who were initially read as positive. Respectively for the initial read and CAD software, sensitivity was 84% and 81%, specificity was 100% and 16%, positive predictive value was 100% and 31%, and negative predictive value was 93% and 65%.*

Conclusions: *The CAD software can be a second reader but should not be used as a stand-alone tool for diagnosis; all MDCT should be reviewed by a radiologist.*

Key Words: *Diagnosis, computer-assisted; False negative reactions; Multidetector computed tomography; Pulmonary embolism; Sensitivity and specificity*

中文摘要

應用多排電腦斷層掃描輔助診斷肺栓塞

M Zimmermann, M Das, CK Kuhl, S Keil

目的：評估在多排電腦斷層掃描（MDCT）中應用電腦輔助診斷（CAD）軟件檢測肺栓塞（PE）的性能。

Correspondence: *Dr Markus Zimmermann, Department of Diagnostic and Interventional Radiology, RWTH Aachen University Hospital, Pauwelsstrasse 30, D-52074 Aachen, Germany.*
Email: mzimmermann@ukaachen.de

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方法：回顧分析連續100例臨床疑PE患者的MDCT血管造影資料。由10名中的2名放射科醫師作出診斷共識（初次閱讀）。將原始數據傳輸到CAD軟件，並由另外兩名資深胸部放射科醫師審查所有CAD標記，以確定CAD的基本真實性和參考標準（最終診斷），並達成共識。標記被歸類為真或假陽性。對於真陽性，所涉及的血管段被分類為肺葉、節段和亞段。將初次和CAD診斷的敏感性、特異性、陰性和陽性預測值進行比較。

結果：在初次閱讀中，27例和73例患者分別為陽性和陰性PE。根據參考標準，73例陰性PE患者中有5例（6.9%）為假陰性，其餘68例為真陰性。CAD軟件分別標記了86例和14例患者有和無PE。根據參考標準，26例為真陽性，57例為假陽性，11例為真陰性，6例為假陰性。CAD軟件檢測到73例最初為陰性的患者中有5例（6.9%）有肺栓子，但CAD軟件在27例最初為陽性的患者中，有6例（22.2%）檢測不到肺栓子。初次閱讀和CAD軟件的靈敏度分別為84%和81%、特異度分別為100%和16%、陽性預測值分別為100%和31%、陰性預測值分別為93%和65%。

結論：CAD軟件可作為第二評估者，但不應被用作獨立診斷工具；所有的MDCT應由放射科醫師審查。

INTRODUCTION

Clinical presentation of pulmonary embolism (PE) can range from asymptomatic to immediate death. PE can occur rapidly and unpredictably and is sometimes difficult to diagnose. Untreated symptomatic PE is associated with a high mortality and thus prompt and accurate diagnosis is needed.[1] Computed tomography (CT) angiography is the first-line imaging modality to detect PE.[2-4] It can also detect other thoracic pathologies such as pleural effusion, pulmonary infiltration, and atelectasis. Multidetector CT (MDCT) increases sensitivity and specificity of PE detection, especially for smaller pulmonary artery branches,[5-7] due to its fast subsecond acquisition, thin collimation, and high spatial resolution.

The Prospective Investigation of Pulmonary Embolism Diagnosis Group recommends the use of CT angiography to detect PE in patients positive for D-dimers with a low-to-moderate clinical probability, and in patients with a high clinical probability.[3,8,9] According to the British Thoracic Society, additional diagnostic test is not necessary after a negative MDCT and no anticoagulation is needed.[10]

In MDCT, thin collimation with 400-800 sections leads to a considerable increase in image data. This may lead to false-negative diagnosis under emergency conditions.[11,12] Computer-assisted diagnosis (CAD) can reduce false-negative diagnosis, especially in patients with severe pre-existing cardiorespiratory disease.[13,14] Nonetheless, CAD has a highly variable sensitivity of 31% to 92% and specificity of 80% to 92 %,[15-17] although it has a second-reader benefit for detection of individual emboli.[16,17] This study aimed to assess the performance of a CAD software in detecting PE and the role of CAD as a second reader.

METHODS

Institutional review board approval was waived for this study. The research protocol was conducted in compliance with Declaration of Helsinki. We retrospectively reviewed CT data of 100 consecutive patients (mean ± standard deviation [SD] age, 60.7 ± 18.3 years) with clinically suspected PE who underwent MDCT angiography of the pulmonary arteries according to the standard protocol.[18] Not all patients had been examined for the blood D-dimer level. MDCT angiography was performed on a 64-detector-row CT through a cranio-caudal direction during inspiratory breath-hold (Table 1). The diagnosis ('initial read') had been made in consensus by two out of 10 radiologists with ≥3 years of experience.

The original CT data were retrieved and transferred to a standard workstation with a viewing software and a CAD software (Siemens Medical Solutions, Malvern [PA], USA). Two other experienced chest radiologists reviewed all CAD markings to determine the ground truth for CAD and the standard of reference (final diagnosis) in consensus. The markings were categorised as true or false positive. For true positive, the involved vessel segment was classified as lobar, segmental, and subsegmental.

The CAD software ran the following key steps: lung

segmentation, candidate generation, feature extraction, and false-positive filtering reduction.[19] Background noise (for evaluation of image quality) was based on the attenuation (in Hounsfield units) at a region of interest of approximately 1 cm^2 within the surrounding air in front of the patient.

Performance of the CAD software and initial radiologists in each patient was compared with the standard of reference (final diagnosis). Sensitivity, specificity, and positive and negative predictive values and their 95% confidence intervals (CI) were calculated. A p value of <0.05 was considered statistically significant.

RESULTS

The mean value of image noise was 12.2 (SD, 2.8; range, 7-19) Hounsfield units. There was no effective limitation due to varying image quality.[20] In the initial read, 27 and 73 patients were positive and negative for PE, respectively. Based on the standard of reference, five (6.8%) of the 73 patients negative for PE were determined to be false negative and the remaining 68 were true negative. The CAD software marked 86 and 14 patients with and without pulmonary emboli, respectively. Based on the standard of reference, 26 were true positive, 57 were false positive, 11 were true negative, and 6 were false negative (Table 2).

Table 1. Protocols of multidetector computed tomography.

Protocol	Value
Iodine concentration (mg/ml)	300
Contrast material volume (ml)	148
Flow rate (ml/s)	4.9
Iodine delivery rate (gI/s)	1.47
Total amount of iodine (g)	44.4
Injection duration (s)	30.2
Tube voltage (kVp)	120
Effective tube current-time product (effective mAs)	120 / 160
Slice collimation (mm)	64 x 0.6
Pitch	1 / 0.9
Slice thickness (mm)	1
Reconstruction increment (mm)	0.7
Reconstruction kernel	Siemens B30f
Window width (Hounsfield units)	400
Window centre (Hounsfield units)	80

Table 2. Performance of initial radiologists and computer-assisted diagnosis compared with the standard of reference.

Standard of reference	No. of patients			
	Initial radiologists		Computer-assisted diagnosis	
	Positive	Negative	Positive	Negative
Positive	27	5	26	6
Negative	0	68	57	11

Respectively for the initial read and CAD software, sensitivity was 84% (95% CI = 67-95%) and 81% (95% CI = 64-93%), specificity was 100% (95% CI = 95-100%) and 16% (95% CI = 8-27%), positive predictive value was 100% (95% CI = 95-100%) and 31% (95% CI = 22-42%), and negative predictive value was 93% (95% CI = 85-98%) and 65% (95% CI = 38-86%).

The CAD software detected pulmonary emboli in five (6.9%) of 73 patients who were initially read as negative. The emboli were located at the subsegmental level of the right inferior (n = 1), left inferior (n = 1) and left superior (n = 1) lobe as well as the segmental level of the right inferior (n = 1) and left superior (n = 1) lobe (Figures 1 and 2). The patient with a segmental PE in the left inferior lobe also showed signs of right ventricular dysfunction (Figure 3). The other four patients were haemodynamically stable with absence of morphological features of right heart failure; they did not receive any treatment.

The CAD software failed to detect pulmonary emboli in 6 (22.2%) of 27 patients who were initially read as positive. The emboli were located at the central (n = 3), segmental (n = 2), and subsegmental (n = 1) levels. There were a mean of 3.8 false-positive CAD markers per patient, mainly caused by vessel walls, pericardium, pulmonary consolidation, or the lobe of the azygous vein (Figure 4).

DISCUSSION

PE may result in morbidity and mortality if left untreated; prompt and accurate diagnosis is necessary.[21] Pulmonary MDCT angiography has been the first-line imaging modality for patients with suspected PE.[2-4,22] Nonetheless, smaller pulmonary emboli especially at segmental and subsegmental arteries can be easily missed under emergency conditions owing to the large amount of data acquired by MDCT with thin collimation. The use of a CAD software as a second reader improves the sensitivity for detection of individual pulmonary emboli that may be missed by radiologists, especially in segmental and subsegmental arteries.[16,17]

Patients diagnosed with PE should immediately be started on intravenous anticoagulation unless

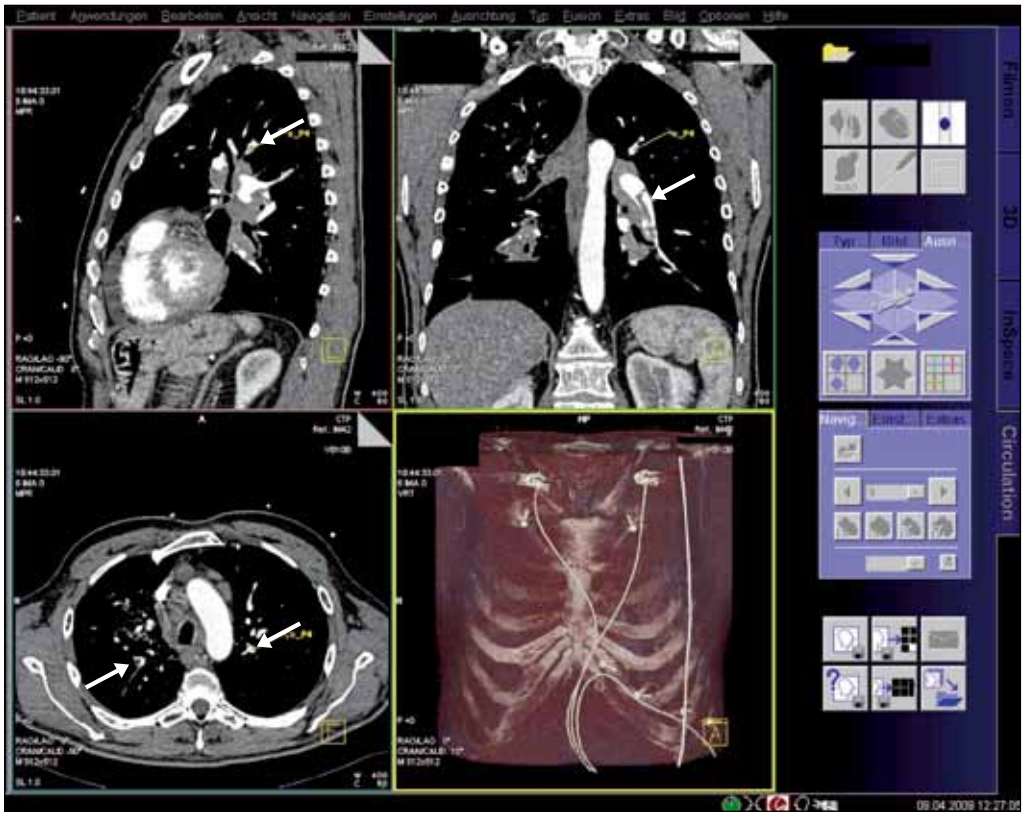

Figure 1. Multidetector computed tomography with computer-assisted diagnosis showing a patient with multiple central, lobar, and segmental pulmonary emboli (arrows).

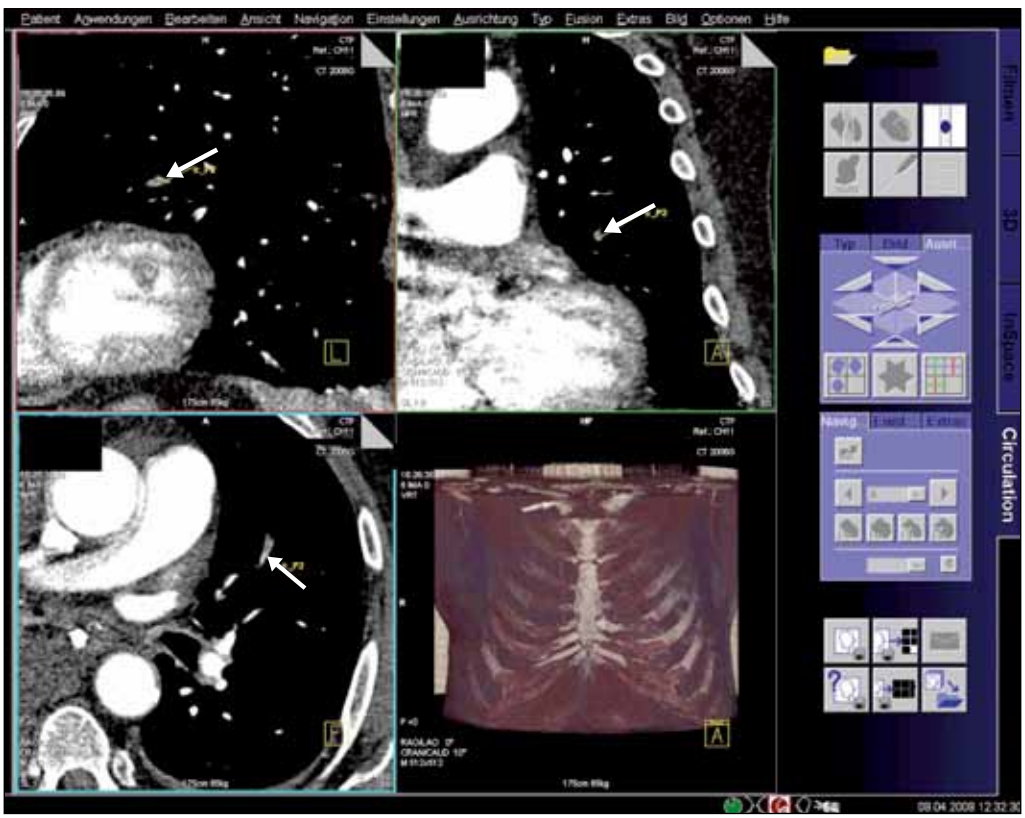

Figure 2. Multidetector computed tomography with computer-assisted diagnosis showing a segmental pulmonary embolus of the lingula that was missed in the initial read (arrows). There is a small pleural effusion and atelectasis dorsobasally.

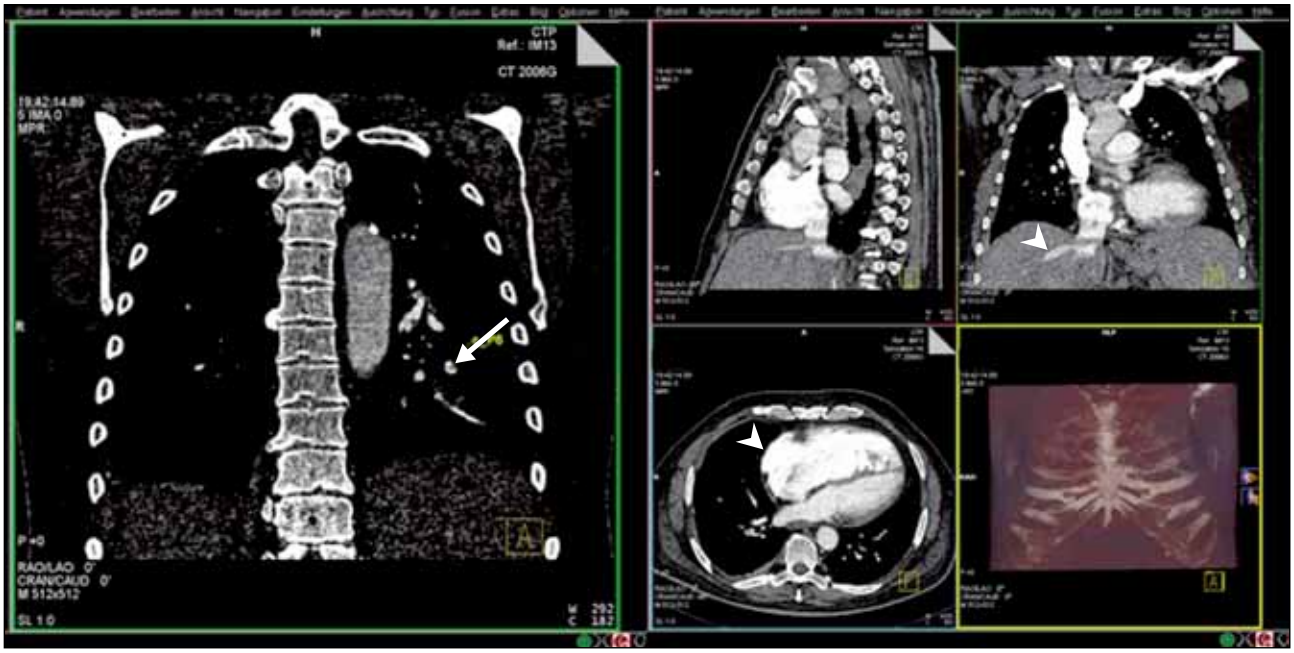

Figure 3. Multidetector computed tomography with computer-assisted diagnosis showing a segmental pulmonary embolus of the left inferior lobe that was missed in the initial read (arrow). There is enlargement of the right atrium and ventricle and contrast material congestion in the hepatic veins secondary to right heart failure (arrowheads).

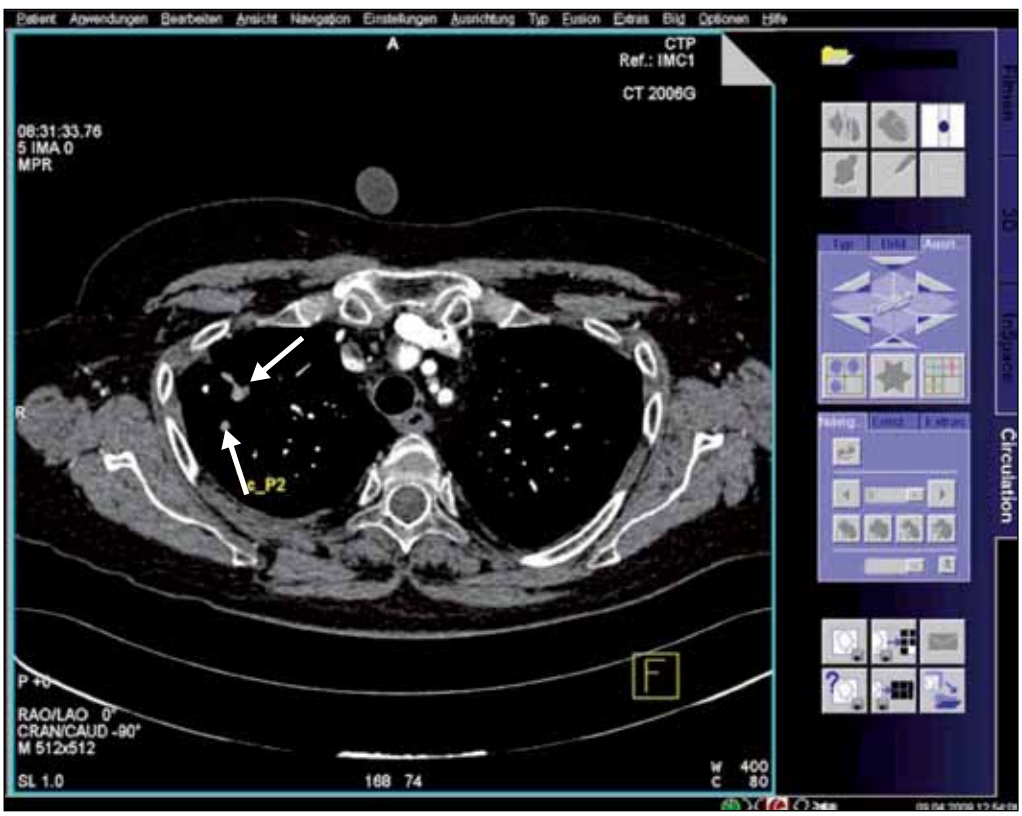

Figure 4. Multidetector computed tomography with computer-assisted diagnosis showing a false-positive diagnosis secondary to lung consolidation in a patient with metastatic malignant melanoma (arrows).

contraindicated to decrease the thromboembolic burden. Hospitalisation with bed rest for 24 to 48 hours is recommended.[1] Nonetheless, it remains controversial about the necessity for treatment of small emboli at a subsegmental level.[23] Small peripheral PE may be clinically relevant in patients with restricted

cardiorespiratory reserve, and may lead to chronic thromboembolic pulmonary hypertension if untreated.[24] The presence of small peripheral emboli suggests the presence of a venous thrombosis in the lower extremities or pelvis, and thus an aggressive work-up. Patients with asymptomatic isolated subsegmental pulmonary emboli should be treated.[12]

The CAD software can detect missed emboli but should not be used as a stand-alone tool for diagnosis. The algorithm of this software was not intended to detect central PE, hence the relatively high rate (18.8%) of false negative. The mean of 3.8 false-positive markers per patient is in line with that reported in one study.[17]

The main limitation of our study was that secondary disorders that might have led to false negative initially were not analysed. Data were analysed retrospectively and may not represent those obtained during daily routine imaging and reading. In addition, the two experienced radiologists who reviewed the CAD markers provided no absolute confidence in CAD marker interpretation.

CONCLUSION

CAD software may detect PE that are initially missed, but it also produces false-negative and false-positive results. It should not be used as a stand-alone tool for diagnosis; all MDCT should be reviewed by a radiologist.

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