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Ventricular short-axis measurements in patients with pulmonary embolism: Effect of ECG-gating on variability, accuracy, and risk prediction

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ABSTRACT

Objective: To assess prospectively the intra- and interobserver variability, accuracy, and prognostic value of right and left ventricular short-axis diameter (RVd and LVd) measurements for risk stratification in patients with pulmonary embolism (PE) using ECG-gated compared to non-gated CT.
Materials and methods: Sixty consecutive patients (33 women; mean age 58.7 ± 10.3 years) with suspicion of PE underwent both non-gated and ECG-gated chest CT. RVd and LVd on four-chamber views and intra- and interobserver agreements were calculated for both protocols. RVd/LVd ratios were calculated and were related to 30-days adverse clinical events using receiver operating characteristics with area-under-the-curve (AUC) analyses.
Results: Both inter- and intraobserver variability showed narrower limits of agreement for all measurements with ECG-gated as compared to non-gated CT. Diameter measurements were significantly lower using non-ECG-gated CT as compared to ECG-gated CT for RVd and LVd (both $p < .05$). The AUC for the RVd/LVd ratio from ECG-gated CT was significantly larger than that from non-gated CT (0.956, 95% CI: 0.768–0.999 versus 0.675, 95% CI: 0.439–0.860; $p = .048$).
Conclusion: RVd and LVd measurements from ECG-gated chest CT show less intra- and interobserver variability and more accurately reflect ventricular function. In our patient cohort ECG-gated chest CT allows better prediction of short-term outcome of patients with acute PE that needs to be validated in a larger outcome study.

1. Introduction

Acute pulmonary embolism (PE) is a life-threatening disease with a 15% death rate in the first three months after diagnosis [1] and a fatal outcome in 30% of untreated patients [2]. Therefore, clinical management calls for selection of high-risk patients who benefit from thrombolysis or embolectomy in addition to anticoagulation therapy for reducing morbidity and mortality [3]. Right ventricular (RV) dysfunction is an independent predictor of mortality in patients with acute PE [4,5]. In clinical routine, RV dysfunction is usually assessed with echocardiography by calculating the ratio of the RV- and left ventricular (LV) short-axis end-diastolic diameter (RVd and LVd) in a four-chamber view [6], and a ratio larger than 0.9 is commonly used as a cut-off to predict poor outcome in patients with PE [3].

Today, contrast-enhanced multi-detector row spiral computed tomography (CT) (i.e., CT pulmonary angiogram) represents the first-line imaging test to diagnose or to rule-out PE [7,8]. Several recent studies have shown that CT also allows for risk stratification of patients with PE [9–16]. Similar to echocardiography, the ratio of short-axis RVd to LVd is used as a surrogate marker for RV dysfunction. At CT, Schoepf et al. [14] proposed a cut-off ratio of 0.9 for predicting an increased mortality in the first 30 days after acute PE.

Interestingly, the majority of CT studies so far evaluating the use of the RVd/LVd ratio for risk stratification in patients with PE have not employed electrocardiography (ECG)-gated CT protocols [9–16]. However, for eliminating motion artifacts of the moving heart, ECG-synchronization is considered mandatory. Obviating ECG-synchronization may result in blurred endocardial borders that often cannot be delineated in an accurate fashion, and interpretation of a non-gated CT with regard to the RVd/LVd ratio might be inaccurate [17]. A recent study showed that ECG-gated

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Table 1
Patient demographics and chest CT findings in the study population.

Patient demographics	
No. of patients	60
Age (years)	58.7 ± 10.3 (46–73)
Female/male	33/27
Body mass index (kg/m^2)	25.5 ± 4.4 (16.7–50.2)
Heart rate during CT (bpm)	77.4 ± 18.2 (46.3–124.1)
Imaging findings	
No pulmonary embolism	39 (65%)
Pulmonary embolism	21 (35%)

bpm, beats per minute.

RV measurements are useful in demonstrating RV dysfunction in patients with PE, and that such measurements from synchronized acquisitions are dependent on embolus location [18].

The purpose of our study was to assess prospectively, in patients with suspicion of PE, the intra- and inter-observer variability and accuracy of RVd and LVd measurements for risk stratification using ECG-gated compared to non-gated chest CT. Additionally, we intended to test in our patient cohort whether ECG-gating improved the prognostic value of the RVd/LVd ratio for predicting early outcome.

2. Material and methods

2.1. Patients

The study protocol was approved by the local ethics committee. All patients gave informed consent after the study details, including the radiation exposure associated with the protocol, were explained.

Between July and December 2006, 60 consecutive patients, enrolled on weekdays between 9am and 6pm, were prospectively included in this study (Table 1). All patients were referred to our department for diagnosing or ruling-out acute PE. The inclusion criteria were elevated serum D-dimers or a high clinical probability of having a PE (based on the Wells score [19]) as well as dyspnea or acute chest pain >5 min within the previous 24 h. All patients irrespective of their mean or regularity of heart rate and irrespective of their ability to suspend respiration during the scan were included. Exclusion criteria included pregnancy, previous adverse reaction to iodinated contrast media, nephropathy (serum creatinine > 1.5 mg/dL), and interference with standard clinical care of patients.

2.2. CT protocol

All examinations were performed on a first generation dual-source CT scanner (Somatom Definition, Siemens Healthcare, Forchheim, Germany).

First, a single non-enhanced low-dose scan (20 mAs) at the level of the ascending aorta was obtained. In this slice, a region of interest (ROI) was set in the lumen of the ascending aorta for timing the start of the contrast-enhanced scan with the contrast arrival. 120 mL contrast material (iopromidum, Ultravist, 300 mg/mL, Bayer Schering Pharma, Berlin, Germany) was administered at a flow rate of 4 mL/s via a 22-gauge needle placed into a vein in the antecubital fossa followed by 30 mL saline solution at the same flow rate (4 mL/s). After reaching the contrast enhancement level of 80 Hounsfield units (HU) in the ROI, a breath-hold command was given and the CT scan was automatically initiated 5 s later. This scan was synchronized to the ECG using the following parameters: collimation 2 × 32 × 0.6 mm with z-flying focal spot for the simultaneous acquisition of 2 × 64 overlapping 0.6 mm slices, gantry rotation time 300 ms, pitch 0.2–0.5 depending on the heart rate, tube potential 120 kV, and tube current time product 300 mAs per rotation. The scan direction was cranio-caudal and included the entire chest. ECG-pulsing for radiation dose reduction was applied in all patients as previously recommended [20]. Then, a second scan (for CT venography) was started 90 s after contrast media injection that was not synchronized to the ECG. No additional contrast material was injected. It started from the level of the aortic valve to the knee. Acquisition parameters were: collimation 32 × 0.6 mm with z-flying focal spot for the simultaneous acquisition of 64 overlapping 0.6 mm slices, gantry rotation time 330 ms, pitch 1.75, tube potential 120 kV, and reference tube current time product 200 mAs per rotation. This scan was performed using automated tube current modulation (CARE Dose4D, Siemens).

The cranial extension of our standard CT venography protocol (normally starting at the diaphragm) to the level of the aortic valve allowed us to obtain data of the ventricles both with and without ECG-gating. Thus, we were able to compare the measurements of ventricular dimensions and volumes between the two protocols within the same patients.

2.3. CT data reconstruction

All data from the first scan was reconstructed with a mono-segment reconstruction algorithm using the data from a quarter rotation of both detectors. Images of the mediastinum and pulmonary arteries including the aorta (mean field of view (FoV) 293 ± 43 mm, image matrix 512 × 512) were reconstructed with a slice thickness of 2 mm (increment 1.5 mm) by using a medium soft-tissue convolution kernel (B30f). Images of the heart were reconstructed with a slice thickness of 0.75 mm, a reconstruction increment of 0.5 mm, and using a soft-tissue convolution kernel (B26f, FoV 178 ± 17 mm, image matrix 512 × 512). Retrospective ECG-gating for phase synchronization was used for this data set, with reconstructions in 5% steps from 0 to 95% of the RR-interval.

The part of the non-gated scan covering the heart was reconstructed using similar parameters as those for the ECG-gated scan (slice thickness 0.75 mm, increment 0.5 mm, B26f, FoV 179 ± 15 mm, image matrix 512 × 512). The part from the diaphragm to the knee was reconstructed with a slice thickness of 2.0 mm (increment 1.5 mm) using a medium soft-tissue convolution kernel (B30f, mean FoV 318 ± 25 mm, image matrix 512 × 512).

Patient information was removed from the data, and all chest images were transferred to a separate workstation (Multimodality Workplace, Siemens) equipped with cardiac post-processing software (Syngo Circulation, Siemens).

2.4. CT data analysis

2.4.1. Imaging findings

All scans were evaluated with regard to the presence or absence of PE in consensus by two experienced observers (with 7 and 10 years of experience in radiology, respectively). The diagnosis of PE was made by the presence of at least one filling defect in the pulmonary arteries.

2.4.2. RVd and LVd measurements

All RVd and LVd measurements of ECG and non-gated CT were performed by two other, independent observers (with 6 and 8 years of experience in cardiovascular radiology, respectively) who were unaware of the imaging findings of the chest and to all clinical information except of the suspicion of PE. After the first reading of both data sets by one observer, the second observer performed the reading of both data sets. The same algorithm was used by the same two observers in a separate, second read-out 6 weeks after the first read-out using a changed case order in both data sets.