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COMPUTED TOMOGRAPHY

Multidetector-CT angiography in pulmonary embolism—can image parameters predict clinical outcome?

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Abstract
Objective To assess if pulmonary CT angiography (CTA) can predict outcome in patients with pulmonary embolism (PE).
Methods Retrospective analysis of CTA studies of patients with PE and documentation of pulmonary artery (PA)/aorta ratio, right ventricular (RV)/left ventricular (LV) ratio, superior vena cava (SVC) diameter, pulmonary obstruction index (POI), ventricular septal bowing (VSB), venous contrast reflux (VCR), pulmonary infarction and pleural effusion. Furthermore, duration of total hospital stay, necessity for/duration of ICU therapy, necessity for mechanical ventilation and mortality were recorded. Comparison was performed by logistic/linear regression analysis with significance at 5%.
Results 152 patients were investigated. Mean duration of hospital stay was 21±24 days. 66 patients were admitted to the ICU; 20 received mechanical ventilation. Mean duration of ICU therapy was 3±8 days. Mortality rate was 8%. Significant positive associations of POI, VCR and pulmonary infarction with necessity for ICU therapy were shown. VCR was significantly associated with necessity for mechanical ventilation and duration of ICU treatment. Pleural effusions were significantly associated with duration of total hospital stay whereas the RV/LV ratio correlated with mortality.
Conclusion Selected CTA findings showed significant associations with the clinical course of PE and may thus be used as predictive parameters.

Keywords Computed tomography · Angiography · Pulmonary embolism · Prognosis · Mortality

Abbreviations

AO	Aorta
AV	Azygos vein
ICU	Intensive care unit
IVC	Inferior vena cava
LV	Left ventricle
PA	Pulmonary artery
pCTA	Pulmonary computed tomography angiography
PE	Pulmonary embolism
POI	Pulmonary obstruction index
RV	Right ventricle
SVC	Superior vena cava
VCR	Venous contrast agent reflux
VSB	Ventricular septal bowing

Introduction

Acute pulmonary embolism (PE) is a disease with variable mortality. More than 90% of patients with PE die within the

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first 3 h because of right heart failure and circulation insufficiency [1] which determines the need for early identification of those individuals at high risk of right-sided heart insufficiency. A number of risk factors for fatal outcome following PE have been identified including age over 70 years, congestive heart failure and other cardiopulmonary diseases [2, 3], presence of meningeal haemorrhage, hypoxaemia, and absence of pharmacological prevention of venous thromboembolism [4]. In PE, preexisting cardiopulmonary dysfunction may impair right ventricular adaptability to an abrupt increase in afterload volume. Thus, right ventricular dysfunction seems to be pathophysiologically more important with respect to prognosis than the pulmonary artery clot load itself [5].

Recent studies demonstrated the importance of pulmonary computed tomography angiography (pCTA) as a first-line imaging technique in patients suspected of having PE [6]. Modern pCTA is capable of clearly illustrating intraluminal clots up to subsegmental arteries [7, 8]. Besides, the method can point out indirect effects of PE to the cardiac level with changes in vessel diameters, interventricular septum deviation, and reflux of contrast medium into the venous system (VCR) [5, 6, 9]. The severity of PE can be evaluated with CTA by using different scoring systems that were derived from conventional angiography studies [10] and adapted to pCTA [11–13]. Recent studies demonstrated different results concerning the association between severity of PE, different clot load scores and patient outcome. While some investigators reported pCTA-derived clot load scores as predictors of severity of PE or PE-related mortality [14], other authors did not find significant predictive power [7, 15–17].

Until now, little attention has been paid to the assessment of possible relationships between image parameters of pCTA and the clinical course of patients with PE apart from mortality. Hence, the purpose of this study was to investigate the prognostic validity of pCTA-derived image findings with respect to necessity and length of therapy on intensive care unit (ICU), necessity of mechanical ventilation, length of hospitalisation in total and mortality in affected patients.

Material and methods

The study was approved by the Ethics Committee of the Ruhr-University of Bochum, Germany

Patient group

Patient selection was retrospectively generated from the institutional diagnostic information system. All patients who had undergone pCTA at our institution for suspected PE between January 2004 and June 2007 and who had been shown to have PE were identified and entered the study group. Indication for performing pCTA had been based on positive results of clinical investigation (determined by revised Wells' score), abnormal findings of laboratory tests (blood gas analysis, D-dimer level, troponin I, brain natriuretic peptide [BNP] [18]), abnormal results of echocardiography/electrocardiogram indicative of acute right heart dysfunction, abnormal findings of lower limb ultrasound, and on results of conventional radiographs suggesting PE. Written informed consent for the pCTA procedure had been given by each patient after full explanation of the examination.

pCTA

All pCTA imaging was obtained using a 16 detector CT system (SOMATOM Sensation 16®, Siemens, Erlangen, Germany). Patients were examined in a supine position with both arms extended above the head. A frontal scout view was acquired at 120 kVp and 50 mA. The angiography was obtained in a caudocranial direction during a single inspiration. Imaging volume ranged from the level of the right diaphragm to a level just above the aortic arch. A collimation of 16×0.75 mm was used with a gantry rotation speed of 0.5 s and a pitch factor of 1.15. Patients underwent imaging with a 120 kVp and 200 mA (100 mAs). For all examinations vessel opacification was provided by intravenous injection of 80 ml of iopamidol (Solutrast 300®, Altana Pharma, Konstanz, Germany) via a cubital vein followed by a saline flush of 40 ml. Flow rate was kept constant at 4 ml/s throughout the procedure. Injections were performed automatically using a commercially available injector (Injektron CT2®, Medtron, Saarbrücken, Germany). Individual contrast optimisation was based on bolus tracking (CARE Bolus®, Siemens, Erlangen, Germany) in the right ventricle using a trigger level of 100 HU. An additional delay of 7 s was added before every examination. For further post-processing thin-slice reconstruction was performed with a slice thickness of 1 mm, an increment of 0.7 mm, and a smooth reconstruction kernel (B30f). Final image analysis was performed on axial images and on coronary maximum intensity projections (MIP) with a slice thickness of 3 and 6 mm, respectively.

Assessment of image parameters

All image analyses were performed on a work station (Leonardo®, Siemens, Erlangen, Germany) by two experienced radiologists (C.M.H., S.P.L.) in consensus. Analyses were based on retrospectively calculated data at the moment of the pCTA.

The following image parameters were measured:

Embolic burden (pulmonary obstruction index = POI)

Emboli were defined as low-attenuation filling defects within the pulmonary arteries. The presence and location of arterial clots and the degree of vessel obstruction was scored using the system published by Qanadli et al. [12] which is based on the number of segmental pulmonary arteries involved, with weight added to an occlusive thrombus. In our analyses, thrombi in a segmental artery received a POI score of 1 whereas thrombi in more proximal arteries received a POI score equal to the number of segmental arteries supplied. If a thrombus in a vessel was occlusive, the POI score in that vessel was multiplied by two. For example, the right upper lobe pulmonary artery supplies three lung segments. Thus, an isolated thrombus in the right upper lobe pulmonary artery received a POI score of 3 and an occlusive thrombus received a POI score of 6. The maximum POI score was 40 for an occlusive thrombus in the main pulmonary artery.

RV/LV ratio

The right ventricular (RV) diameter was measured in the diastole on the transverse section at the level of the tricuspid valve from the inner wall to the inner wall at the widest point in the chamber. The left ventricular (LV) diameter was measured on transverse images that showed the mitral valve and, like the RV diameter, in the largest distance between the inner aspect of the interventricular septum and the free wall of the left ventricle. The RV/LV ratio was then calculated from these measurements.

Diameters of SVC, AO, PA and AO/PA ratio

The diameter of the superior vena cava (SVC) was measured on the transverse level which showed the entrance of the azygos vein (AV) into the SVC. Vascular measurements of the aorta (AO) and the pulmonary artery (PA) were obtained on adjusted multiplanar reformatted images in the plane that was perpendicular to the long axis of the vessel being considered and were acquired by using electronic callipers. The diameter of the main PA lumen was measured proximal to its branching division whereas measurements of the aorta were taken at the level of the middle third of its ascending portion. The ratio of the main PA diameter to the AO diameter (AO/PA-ratio) was calculated from these figures.

Ventricular septal bowing

The presence or absence of convex ventricular septal bowing (VSB) was subjectively judged on transverse CT scans. VSB was documented as positive if any image demonstrated ventricular septal bowing leftward into the left ventricle.

Reflux of contrast medium into the inferior vena cava and the azygos vein

If there was VCR into the proximal sections of the inferior vena cava (IVC) and/or the AV, this indicator was recorded to be positive.

Further CT observations

The subsequent observations were also recorded if present: pleural effusion and pulmonary consolidation consistent with PE-related lung infarction.

Clinical patient parameters

Based on patient records the following clinical parameters were documented: patient sex and age, duration of total stay in hospital, necessity for and duration of stay on the ICU, necessity for mechanical ventilation within 48 h of acquisition of CT, and mortality during the initial hospital stay.

Statistical analysis

All calculations were performed on a standard PC using PASW statistics, release 18.0.0 (SPSS, Chicago, IL, U.S.A.). Patient age, RV and LV diameter, RV/LV ratio, AO and PA diameter, PA/AO ratio, SVC diameter, POI score, duration of stay in hospital and duration of stay on the ICU are expressed as mean value±standard variation (range). Patient sex, necessity for treatment on the ICU, necessity for mechanical ventilation, VSB, VCR into the IVC and/or AV, presence of pleural effusion and PE-related lung infarction were documented as absolute numbers (percentages). Prognostic relevance of image parameters regarding clinical observations was assessed with uni- and multivariate logistic or linear regression analysis. Regression coefficients and odds ratios were calculated and 95% confidence intervals were given. Statistical significance of all tests was set at a p level of less than 5%.

Results

Patient group

A total of 152 patients were included in the study group. Eighty-four patients (55%) were male and mean age was 62±17 years (22–95 years). Mean duration of hospital stay was 21±24 days (2–180 days). Sixty-six patients (43%) were admitted on the ICU with 20 patients (13%) receiving mechanical ventilation. Mean duration of ICU therapy was 3±8 days (0–60 days). Mortality in the study group was 8%

(12 patients). Table 1 displays image findings and calculated ratios of the study group. Neither patient sex nor age had any significant impact on necessity or duration of ICU treatment, necessity for mechanical ventilation, duration of total hospital stay, or mortality.

Necessity of treatment on ICU

Table 2 displays the relationship of image parameters and necessity for being treated on the ICU. In univariate logistic regression analysis, a significant positive correlation between necessity of ICU treatment and PA/AO ratio (p=0.017), RV/LV ratio (p=0.030), POI (p<0.001), and VCR into the IVC (p=0.001) could be demonstrated whereas in multivariate logistic regression analysis only POI (p=0.020), VCR into the IVC (p=.0021), and presence of pulmonary infarction (p=0.028) showed significant results.

Necessity for application of mechanical ventilation

The necessity for application of mechanical ventilation was significantly correlated with VCR into the IVC in uni- (p=0.003) and multivariate logistic regression analysis (p=0.008). All other image parameters showed no significant impact on the need for mechanical ventilation. Table 3 summarises these results.

Table 1 Results of image parameters within the study group (n=152 patients)

Image parameter	Results[a]
AO (diameter)	35±5 mm (23–50 mm)
PA (diameter)	31±5 mm (20–55 mm)
PA/AO-ratio	0.9±0.2 (0.5–1.8)
RV (diameter)	44±8 mm (22–62 mm)
LV (diameter)	41±9 mm (16–65 mm)
RV/LV ratio	1.1±0.4 (0.5–3.1)
POI	37±25% (5–85%)
SVC (diameter)	20±4 mm (9–30 mm)
VSB	85 positive (56%), 67 negative (44%)
Contrast agent reflux into the VA	95 positive (63%), 57 negative (37%)
Contrast agent reflux into the IVC (assessable in 143/152 patients)	84 positive (59%), 59 negative (41%)
Pleural effusion	69 positive (45%), 83 negative (55%)
Pulmonary infarction	54 positive (36%), 98 negative (64%)

[a] Numerical variables are displayed as mean value±standard deviation (range)

AO aorta; *IVC* inferior vena cava; *LV* left ventricle; *PA* pulmonary artery; *POI* pulmonary obstruction index; *RV* right ventricle; *SVC* superior vena cava; *VA* azygos vein; *VSB* ventricular septal bowing

Table 2 Impact of image parameters on the necessity for treatment in the intensive care unit

	Patients who were treated in the ICU (n=66)	Patients who were not treated in the ICU (n=86)	Univariate logistic regression analysis		Multivariate logistic regression analysis		
			p value	Regression coefficient (95% confidence interval)	p value	Regression coefficient	Odds ratio (95% confidence interval)
PA/AO ratio	0.95±0.19 (0.61–1.84)	0.87±0.17 (0.54–1.65)	0.017	0.521 (0.093–0.949)	0.215	1.377	3.963 (0.449–34.964)
RV/LV ratio	1.22±0.49 (0.49–3.13)	1.08±0.29 (0.53–2.14)	0.030	0.223 (0.022–0.425)	0.817	–0.132	0.877 (0.286–2.683)
POI	45.47±26.72% (5–85%)	30.03±21.04% (5–85%)	<0.001	0.006 (0.003–0.009)	0.020	0.021	1.022 (1.003–1.040)
SVC (diameter)	21.0±3.9 mm (10.2–28.8 mm)	20.0±3.9 mm (9.3–30.3 mm)	0.143	0.151 (–0.052–0.354)	0.354	0.461	1.585 (0.598–4.201)
VSB	40 (61%)	45 (52%)	0.311	0.083 (–0.078–0.243)	0.582	–0.242	0.785 (0.332–1.857)
Contrast agent reflux into the VA	44 (67%)	51 (59%)	0.356	0.077 (–0.088–0.242)	0.875	0.065	1.067 (0.472–2.413)
Contrast agent reflux into the IVC (assessable in 143/152 patients)	45/61 (74%)	39/82 (48%)	0.001	0.265 (0.103–0.426)	0.021	0.994	0.370 (0.159–0.862)
Pleural effusion	31 (47%)	38 (44%)	0.735	0.028 (–0.133–0.188)	0.136	–0.643	0.526 (0.226–1.224)
Pulmonary infarction	18 (27%)	36 (42%)	0.063	–0.156 (–0.322–0.009)	0.028	1.001	2.721 (1.115–6.641)

AO aorta; *ICU* intensive care unit; *IVC* inferior vena cava; *LV* left ventricle; *PA* pulmonary artery; *POI* pulmonary obstruction index; *RV* right ventricle; *SVC* superior vena cava; *VA* azygos vein; *VSB* ventricular septal bowing

Table 3 Impact of image parameters on the necessity for application of mechanical ventilation

	Patients who were treated with mechanical ventilation (n=20)	Patients who were not treated with mechanical ventilation (n=132)	Univariate logistic regression analysis		Multivariate logistic regression analysis		
			p value	Regression coefficient (95% confidence interval)	p value	Regression coefficient	Odds ratio (95% confidence interval)
PA/AO ratio	0.90±0.15 (0.63–1.15)	0.90±0.19 (0.54–1.84)	0.898	−0.019 (−0.317–0.278)	0.461	−1.265	0.282 (0.010–8.165)
RV/LV ratio	1.19±0.60 (0.49–3.13)	1.13±0.35 (0.53–2.83)	0.523	0.045 (−0.094–0.185)	0.690	0.283	1.327 (0.331–5.326)
POI	35.35±27.11% (5–78%)	36.95±24.55% (5–85%)	0.789	0	0.856	−0.002	0.998 (0.972–1.014)
SVC (diameter)	21.4±3.2 mm (14.7–27.2 mm)	20.3±4.0 mm (9.3–30.3 mm)	0.217	0.087 (−0.052–0.225)	0.346	0.672	1.959 (0.483–7.939)
VSB	8 (40%)	77 (58%)	0.125	−0.085 (−0.194–0.024)	0.247	−0.776	0.460 (0.124–1.711)
Contrast agent reflux into the VA	14 (70%)	81 (61%)	0.461	0.042 (−0.070–0.155)	0.743	0.202	1.224 (0.366–4.087)
Contrast agent reflux into the IVC (assessable in 143/152 patients)	17/19 (89%)	67/124 (54%)	0.003	0.168 (0.057–0.280)	0.008	2.160	8.668 (1.741–43.143)
Pleural effusion	12 (60%)	57 (43%)	0.161	0.078 (−0.031–0.186)	0.232	0.709	2.031 (0.635–6.499)
Pulmonary infarction	8 (40%)	46 (35%)	0.656	0.026 (−0.088–0.140)	0.853	0.113	1.120 (0.339–3.699)

AO aorta; *IVC* inferior vena cava; *LV* left ventricle; *PA* pulmonary artery; *POI* pulmonary obstruction index; *RV* right ventricle; *SVC* superior vena cava; *VA* azygos vein; *VSB* ventricular septal bowing

Duration of treatment on the ICU and duration of total hospital stay

Table 4 shows the relationship between image parameters and the duration of ICU treatment/total hospital stay. In univariate and multivariate linear regression analyses, significant associations between duration of ICU treatment and VSB (p=0.030/0.048) and VCR into the IVC (p=0.050/0.018) could be demonstrated. The latter was positively correlated with the duration of ICU treatment (regression coefficient: 3.636), whereas VSB showed a negative correlation (regression coefficient: −3.124). All other image parameters did not reveal any significant impact on duration of ICU treatment.

Univariate analysis revealed significant positive correlation between existence of pleural effusion and duration of hospital stay (p=0.001) whereas VSB was significantly correlated in a negative way (p=0.015, regression coefficient: −9.619). However, in multivariate linear regression analysis pleural effusion remained the only parameter to show a significant impact (p=0.009) on the duration of total hospital stay.

Mortality

In univariate logistic regression analysis, RV/LV ratio (p<0.001), diameter of SVC (p=0.015), VCR into the AV (p=0.030) and VCR into the SVC (p=0.015) were significantly associated with mortality whereas in multivariate analysis, RV/LV ratio alone showed a significant positive association to mortality (p=0.019). A compilation of these results is displayed in Table 5.

Table 6 summarises all results of the multivariate regression analyses indicating that the necessity for ICU therapy showed a significant positive correlation to POI and pulmonary infarction and a negative correlation to VCR into the IVC. Moreover, necessity for mechanical ventilation and duration of ICU treatment were significantly associated with VCR into the IVC. Finally, duration of total hospital stay was correlated with presence of pleural effusion whereas mortality revealed a single positive correlation with RV/LV ratio.

Discussion

pCTA has practically become the first-line technique for imaging of pulmonary circulation in patients suspected of having PE [19–21]. Although the development of multidetector CT has led to faster image acquisition and improved image quality little is known about the prognostic properties of pCTA with respect to the clinical course of affected patients. Moreover, the finding of a small isolated

Table 4 Impact of image parameters on duration of treatment in the intensive care unit and on duration of total hospital stay

	Duration of treatment in the intensive care unit				Duration of total hospital stay			
	Univariate linear regression analysis		Multivariate linear regression analysis		Univariate linear regression analysis		Multivariate linear regression analysis	
	p value	Regression coefficient (95% confidence interval)	*p* value	Regression coefficient (95% confidence interval)	*p* value	Regression coefficient (95% confidence interval)	*p* value	Regression coefficient (95% confidence interval)
PA/AO ratio	0.353	3.295 (−3.693–10.284)	0.402	3.294 (−4.451–11.038)	0.189	14.144 (−7.044–35.332)	0.468	7.318 (−12.565–27.201)
RV/LV ratio	0.614	−0.839 (−4.122–2.443)	0.392	−1.771 (−5.854–2.312)	0.290	−5.350 (−15.303–4.602)	0.759	−1.626 (−12.109–8.856)
POI	0.894	−0.004 (−0.055–0.048)	0.908	0.004 (−0.062–0.070)	0.702	−0.031 (−0.188–0.127)	0.402	0.072 (−0.097–.241)
SVC (diameter)	0.439	1.286 (−1.987–4.559)	0.406	1.488 (−2.041–5.017)	0.555	2.986 (−6.975–12.946)	0.885	−0.663 (−9.723–8.397)
VSB	0.030	−2.823 (−5.369–−0.277)	0.048	−3.124 (−6.216–−0.032)	0.015	−9.619 (−17.329–−1.910)	0.141	−5.949 (−13.887–1.990)
Contrast agent reflux into the VA	0.642	0.625 (−2.026–3.275)	0.853	0.277 (−2.672–3.225)	0.312	−4.123 (−12.161–3.915)	0.774	−1.101 (−8.670–6.468)
Contrast agent reflux into the IVC (assessable in 143/152 patients)	0.050	2.723 (0.001–5.462)	0.018	3.636 (0.622–6.651)	0.693	1.404 (−5.612–8.421)	0.423	3.143 (−4.597–10.883)
Pleural effusion	0.135	1.948 (−0.612–4.508)	0.077	2.674 (−0.299–5,647)	0.001	12.642 (5.069–20.215)	0.009	10.254 (2.621–17.887)
Pulmonary infarction	0.531	−0.852 (−3.531–1.828)	0.099	−2.580 (−5.654–0.493)	0.129	6.248 (−1.849–14.344)	0.564	−2.310 (−10.202–5.582)

AO aorta; *IVC* inferior vena cava; *LV* left ventricle; *PA* pulmonary artery; *POI* pulmonary obstruction index; *RV* right ventricle; *SVC* superior vena cava; *VA* azygos vein; *VSB* ventricular septal bowing

Table 5 Impact of image parameters on patient mortality

	Patients who died during hospital stay (*n*=12)	Patient who survived during hospital stay (*n*=140)	Univariate regression analysis		Multivariate regression analysis		
			p value	Regression coefficient (95% confidence interval)	*p* value	Regression coefficient	Odds ratio (95% confidence interval)
PA/AO ratio	0.92±0.19 (0.63–1.24)	0.90±0.18 (0.54–1.84)	0.753	0.038 (−0.199–0.275)	0.926	−0.193	0.824 (0.014–48.139)
RV/LV ratio	1.52±0.63 (0.88–3.13)	1.11±0.35 (0.49–2.83)	<0.001	0.193 (0.086–0.300)	0.019	1.938	6.947 (1.382–34.925)
POI	37.42±24.36% (13–75%)	36.68±24.93% (5–85%)	0.922	0	0.386	−0.014	0.986 (0.956–1.018)
SVC (diameter)	20.7±4.0 mm (13.9–27.5 mm)	20.4±3.9 mm (9.3–30.3 mm)	0.015	0.114 (0.022–0.206)	0.802	−0.228	0.796 (0.134–4.741)
VSB	7 (58%)	78 (56%)	0.862	0.008 (−0.080–0.095)	0.620	−0.441	0.644 (0.113–3.673)
Contrast agent reflux in VA	11 (92%)	84 (60%)	0.030	0.098 (0.010–0.187)	0.202	−1.427	0.240 (−0.027–2.154)
Contrast agent reflux into the IVC (assessable in 143/152 patients)	11/12 (92%)	73/131 (56%)	0.015	0.114 (0.022–0.206)	0.125	−1.723	0.179 (−0.020–1.615)
Pleural effusion	6 (50%)	63 (45%)	0.741	0.015 (−0.073–0.102)	0.409	−0.606	0.545 (0.129–2.300)
Pulmonary infarction	4 (33%)	50 (36%)	0.870	−0.008 (−0.098–0.083)	0.812	−0.188	0.829 (0.176–3.912)

AO aorta; *IVC* inferior vena cava; *LV* left ventricle; *PA* pulmonary artery; *POI* pulmonary obstruction index; *RV* right ventricle; *SVC* superior vena cava; *VA* azygos vein; *VSB* ventricular septal bowing

Table 6 Comparison of image parameters and steps of clinical course (Summary of multivariate regression analyses)

	Treatment on ICU	Mechanical ventilation	Duration of ICU treatment	Duration of total hospital stay	Mortality
PA/AO ratio	0	0	0	0	0
RV/LV ratio	0	0	0	0	+
POI	+	0	0	0	0
SVC (diameter)	0	0	0	0	0
VSB	0	0	−	0	0
Contrast agent reflux into the VA	0	0	0	0	0
Contrast agent reflux into the IVC	−	+	+	0	0
Pleural effusion	0	0	0	+	0
Pulmonary infarction	+	0	0	0	0

+ = significant positive correlation, − = significant negative correlation, 0 = no significant impact

AO aorta; *IVC* inferior vena cava; *LV* left ventricle; *PA* pulmonary artery; *POI* pulmonary obstruction index; *RV* right ventricle; *SVC* superior vena cava; *VA* azygos vein; *VSB* ventricular septal bowing

clot at pCTA may be difficult to correlate with results of other imaging techniques making the clinical importance of such finding uncertain [10]. Thus, some authors have underlined the necessity of objectively measuring efficacy of pCTA in PE by correlating it to patient outcome. Based on conventional angiography findings, score systems were developed that aimed at quantifying the degree of pulmonary artery obstruction. Despite their methodical differences, these scores revealed good correlations with one another. By now, the pCTA scores suggested by Mastora at al. [11] and Qanadli and co-workers [12] have gained the broadest attention. Although scoring the degree of pulmonary vessel obstruction based on pCTA in PE has become a routine procedure, its value for prediction of clinical outcomes is still unclear. While some investigators [14, 22] found significant correlations between pulmonary clot load score and mortality, others failed to do so and, instead, documented the clot load score to be a poor predictor of mortality [12, 15–17, 23]. In our study, calculation of POI did not show any significant impact on mortality rates. This is in accordance with three recent publications [16, 17, 23] which reported that pulmonary clot load scores indicated the extent of the clot but did not predict right ventricular failure or death. However, we were able to document a significant positive correlation between POI and necessity for ICU treatment. Furthermore, VCR into the IVC and presence of pulmonary infarcts were also correlated with treatment on the ICU. Due to the retrospective character of our study, one might speculate that the subjective impression of higher clot loads with pulmonary infarctions might presumably have influenced final decision making with regard to whether or not to treat a patient in the ICU.

Lung infarctions have been identified to be associated with significantly lower mortality rates both during initial therapy and after discharge [24]. In our study, lung infarcts were not correlated with mortality which might be due to the small sample size. Besides, the incidence of lung infarcts was documented to be up to 50% [24], which is somewhat higher than in our group. A possible explanation might be the fact that the diagnosis of lung infarcts in our population was based on image findings alone whereas Lobo et al. defined them as “pleuritic pain or hemoptysis” [24].

VCR is a result of tricuspid valve insufficiency, right ventricular dilatation and reduced right ventricular output. In an analysis by Collomb et al. [23], no significant differences between patients with severe and non-severe PE could be observed regarding VCR. However, Ghaye and co-workers [17] were able to discriminate between PE survivors and non-survivors based on VCR. Ghuysen et al. and Ghaye et al. also documented a significant correlation between mortality and VCR into the IVC [16, 17]. Although we did not find a significant impact of VCR on mortality in multivariate regression analysis, our results may possibly strengthen the preceding findings by indicating a significant correlation between VCR into the IVC and the duration of ICU treatment and the necessity for mechanical ventilation, respectively. One might speculate that VCR into the IVC could therefore be used as an indicator of clinically relevant right ventricular dysfunction hence influencing the course during ICU therapy. It is important to point out that – for accurate evaluation of the IVC – the CT scan should cover the upper abdomen. Apart from VCR to the IVC we also documented if contrast agent was observed within the AV. Although incidence was high, VCR into the AV did not reveal any significant impact on the clinical course of affected patients.

Beside VCR, dilatation of central veins can be observed in some patients with PE [25]. Ghuysen et al. documented a significant correlation of SVC diameter with mortality [16]. In our analysis, diameter of the SVC showed a wide range and did not significantly correlate with any of the tested parameters. Possible explanations might be that the size of the SVC is strongly dependent on breathing and that a marked dilatation can be provoked by deep inspiration. Thus, time-consuming measurement of the SVC diameter

with respect to prognostic assessment of patients with PE cannot be wholeheartedly recommended.

Under physiological conditions, abrupt obstruction of pulmonary blood flow of more than 30% leads to acute pulmonary hypertension [5]. Low output of the right ventricle may be compensated for by the Frank-Starling mechanism but can result in an increase in myocardial oxygen demand which may lead to left ventricular dysfunction [26]. In addition to right ventricular dilatation, both factors can cause VSB. Finally, a vicious circle with a further decrease in left ventricular preload resulting in cardio-respiratory collapse may result [27, 28]. Echocardiography studies revealed significant associations of VSB and mortality due to PE [3, 26, 29]. However, two recent publications [15, 22] which explicitly investigated VSB in pCTA did not find this sign to be significantly correlated with mortality. Moreover, Araoz et al. documented a high interobserver variability concerning evaluation of VSB. These contradictory results may be explained by the fact that echocardiography is, in comparison to pCTA, a dynamic method. In pCTA, flattening of the ventricular septum may be mistaken for septal bowing and the incidence of VSB might therefore be overestimated. In our study, VSB was observed in 56% of patients. In accordance with the studies mentioned above, we were not able to document a significant impact of VSB on mortality, necessity for ICU treatment, or mechanical ventilation. In our patient group, evaluation of VSB was solely based on standard transverse CT planes which reflects the pragmatic method of image interpretation in suspected PE in daily routine. A more precise evaluation of the interventricular septum might have been achieved by three-dimensional image reconstructions and by ECG-triggering of data acquisition in order to reduce motion artefacts. However, this is more time-consuming and might lead to higher radiation exposure of affected patients.

Acute PE with pulmonary hypertension may lead to right ventricular enlargement resulting in an elevated RV/LV ratio. The average value in our study group was 1.1 with a wide range of 0.5 to 3.1 reflecting the broad spectrum of patients included in our population. RV/LV ratio was the only parameter to show a significant correlation with mortality in multivariate regression analysis which underlines the necessity of calculating the RV/LV ratio in patients with PE in order to estimate their prognosis. Our results are in accordance with those of previous studies [16, 17, 22, 30]. On the other hand, Araoz and co-workers [15] did not find a significant correlation between RV/LV ratio and mortality which might be explained by the fact that five different CT systems and no dedicated pCTA protocol were used in this study. Like the presence of VSB, evaluation of the RV/LV ratio was performed based on transverse planes in our study group. In echocardiography, right ventricular dysfunction can be assessed by documentation of hypokinesis, straightening, and paradox septal deviation. RV/LV ratio is calculated based on measurements in four-chamber-views and shows positive correlations with severity of PE and mortality, respectively [27, 29]. Quiroz et al. [31] compared measurements on transverse CT sections with those on reconstructed four-chamber CT-views and reported that the RV/LV ratio of more than 0.9 was significantly associated with mortality when measured on a four-chamber view but not on transverse sections. Our results might indicate that in a routine setting of performing pCTA, evaluation of standard axial planes is the best pragmatic compromise between rapid data reconstruction and maximum image validity.

Beyond the RV/LV ratio, the diameter ratio between the thoracic aorta and the pulmonary artery can be used to evaluate the degree of pulmonary hypertension in PE. However, in our study group the PA/AO ratio did not show a significant impact on any of the clinical parameters which is in accordance with the findings of van der Meer and colleagues [22]. Thus, calculation of the PA/AO ratio cannot be recommended for prognostic assessment of patients with PE.

Limitations of our study include the retrospective character which always comprises the possibility of undetected data-inherent flaws. Moreover, a potential impact of other parameters on the clinical course of patients apart from those we investigated was not analysed. Because the average patient age in our study group was high a substantial number of patients presumably had multiple other diseases potentially influencing the aetiology and severity of PE [32]. Furthermore, categorisations of patients with respect to VCR and VSB were intrinsically not immune to subjectivity. Although the combination of a negative pCTA and normal venous ultrasound imaging safely excludes the diagnosis of PE in an emergency department setting [33], a number of patients with PE but false-negative CT findings might have been missed by our selection criteria [32, 34]. Moreover, some studies have shown that, despite the use of bolus tracking, the quality of pCTA images is dependent on patient characteristics [35], protocol parameters [36–38] and motion artefacts [38, 39] hence potentially influencing image quality and analysis in our patient population. Finally, the study group was of only moderate size and the number of deaths was small. It could be speculated that some results that were significant in univariate analysis would have been statistically significant in multivariate analysis too, if a larger patient group had been analysed.

In conclusion, our results indicate that selected pCTA findings may be used as prognostic parameters in patients with PE. Apart from mortality, the clinical course including necessity for ICU treatment and mechanical ventilation and

the duration of hospital treatment showed significant correlations with pCTA findings and measurements. For daily practice, evaluation of POI, RV/LV ratio, and VCR into the IVC may be recommended apart from assessment of other chest abnormalities including pleural effusions and pulmonary infarctions for prognostic estimations in patients with proven PE.

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