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ORIGINAL PAPER

CT PULMONARY ANGIOGRAPHY – PATIENT MANAGEMENT APPROACH WITH RADIATION EXPOSURE REDUCTION

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Abstract

Background: To determine the difference in the radiation exposure of patients undergoing conventional single-energy computed tomography pulmonary angiography (SECTPA) and dual-energy CT pulmonary angiography (DECTPA) and determination of the benefits of both methods in the diagnosis of pulmonary embolism (PE). **Material and Methods:** In this single-center retrospective study, 105 consecutive CTPA examinations performed on dual-source dual-energy CT scanner November 2018–December 2020 at St. Michael's University Hospital Radiodiagnostic Clinic, Bratislava, Slovakia were reviewed for detection of acute PE and dose-length product (DLP) in each examination was noted and compared in SECTPA and DECTPA. The 105 examinations included 95 patients (mean [M] = 60.5 years, range 20–88 years). **Results:** Of the 95 examined patients, 92 had an initial examination, of whom 22 had confirmed acute PE (23.9% of initially examined patients, 11 by SECTPA, and 11 by DECTPA), in 70 patients (i.e., 76.1%) PE was not present. The DLP in DECTPA was M = 344.4 mGy×cm, and in SECTPA M = 176.7 mGy×cm. **Conclusions:** Mean DLP in DECTPA was almost 2-times higher than in SECTPA (with a statistically significant difference, $p < 0.001$), while in three-quarters of patients, acute PE was not confirmed, which is in the era of CTPA overuse unnecessary radiation exposure. However, DECTPA with iodine perfusion maps is superb in the follow-up of patients with confirmed PE by detecting small chronic subsegmental PE and thus preventing chronic complications in the form of chronic thromboembolic pulmonary hypertension, which, if untreated, is fatal. Med Pr Work Health Saf. 2025;76(1)

Key words: pulmonary embolism, subsegmental pulmonary embolism, dual-energy CT, single-energy CT, radiation exposure, dose-length product

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INTRODUCTION

Pulmonary embolism (PE) is a relatively frequent and life-threatening disease that represents a severe medical problem with a high rate of hospitalization and death. Therefore, a quick and correct diagnosis is essential in managing patients with PE. In addition to proper clinical diagnosis, an examination with imaging methods is necessary, of which the method of choice for confirmation or exclusion of PE is computed tomography pulmonary angiography (CTPA). Due to the increasing availability of non-invasive imaging, especially CTPA, there is a tendency in clinical examination to assume PE more often than in the past, leading to the overuse of CTPA examinations [1,2].

Modern devices enabling examination with 2 energies dual-energy CT (DECT) scanners enable the detection of even small subsegmental embolization during DECT pulmonary angiography (DECTPA) with favorable results [3,4], but potentially at the cost of higher radiation exposure to the patient. There is the overuse of CT examinations in diagnosing PE in daily practice. Therefore, DECTPA in patients without PE represents an unnecessary excessive radiation load with risks of unwanted biological effects.

The aim of this study was to determine the difference in the radiation exposure of patients undergoing conventional single-energy CTPA (SECTPA) and DECTPA, while based on meta-analysis published in 2021 [5] the sensitivity of SECTPA and DECTPA in clinically significant lobar and segmental PE is the same.

MATERIAL AND METHODS

To this single-center retrospective study were enrolled all patients examined at St. Michael's University Hospital Radiodiagnostic Clinic, Bratislava, Slovakia 1 November 2018–31 December 2020. During this period, 105 CTPA examinations were performed in 95 adult patients (47 males, 48 females), M = 60.5 years (median [Me] = 65 years, range 20–88 years).

Patients were examined on a dual-source DECT scanner Siemens Somatom Definition Flash (Siemens Healthineers AG, Forchheim, Germany) with 2 detector rows, each with 128 slices. In conventional SECTPA the voltage on the X-ray tube was fixed at 100 kV, tube current of reference 150 mAs (effective mAs modulated by CARE Dose4D), pitch of 1.2 and rotation time 0.28 s; in DECTPA the voltage on the X-ray tubes was set by manufacturer to 100 kVp for tube A and 140 kVp for tube B, tube current of reference 150 mAs for tube A and 116 mAs for tube B (effective mAs modulated by CARE Dose4D), pitch of 0.7 and rotation time 0.33 s. In initial, first examination in suspicion for acute PE individual doctors in charge of CT selected the examination technique (SECTPA or DECTPA) in each patient, i.e., patients were randomly examined with SECTPA or DECTPA. Patients undergoing repeated follow-up examination preferably examined with DECTPA.

For each examination, automatically calculated dose-length product (DLP) and volume computed tomography dose index ($CTDI_{vol}$) was recorded.

Statistical analysis was performed with commercially available statistic software (Microsoft Excel [Microsoft Corporation, Redmond, Washington, USA] with open-source statistical add-in BESH Stat). For assessment of statistical significance difference, a non-parametric Mann-Whitney test was performed. Non-parametric test was chosen because of small sample size and non-Gaussian distribution of data and the presence of outliers, especially in data group of DECTPA.

RESULTS

Of the 95 examined patients, 92 patients had initial examination (45 males, 47 females) of whom 22 had confirmed acute PE (13 males, 9 females), which represents 23.9% of initially examined patients, in 70 patients (32 males, 38 females), i.e., 76.1%, PE was not present.

Of the 92 initially examined patients 8 patients had follow-up examination – 7 patients had 1 follow-up examination and 1 patient had 2 follow-up examinations. Three patients were examined only with follow-up examinations after diagnosed PE at another hospital radiology department – 2 patients had 1 and 1 patient had 2 follow-up examinations.

Of the 92 initially examined patients 59 patients (64.1%) underwent DECTPA, 33 patients (35.9%) were examined with SECTPA. With DECTPA 11 cases of acute PE were detected, which represents 18.6% of DECTPA examinations; with SECTPA also 11 cases of acute PE were detected, which represents 33.3% of SECTPA examinations.

Location of acute PE was in 5 patients in main pulmonary arteries, in 7 patients in lobar arteries and in 10 patients in segmental and subsegmental pulmonary arteries, whereas 1 patient had isolated subsegmental PE.

Of overall 105 examinations 67 examinations were DECTPA (63.8%) and 38 examinations were SECTPA (36.2%) (Table 1).

From clinical signs in suspicion of acute PE 4 major signs include deep vein thrombosis (DVT), dyspnea, chest pain and elevated D-dimer in blood test. Out of 92 initially examined patients in 11 patients no data were provided, since these were outpatients from private health care. In the rest of 81 patients all 4 clinical signs were provided in 65 patients, in 16 patients ≥1 sign was not stated. Patients had present ≥1 sign or different combinations of clinical signs. The majority of patients had elevated D-dimer; the second most common sign was dyspnea. The combination of all 4 clinical signs was present only in 4 patients; all of them had confirmed acute PE (Table 2). Nevertheless, presented clinical signs had no effect on radiation exposure.

Total DLP in DECTPA examination was 257–612 mGy×cm (M = 344.4 mGy×cm, Me = 319 mGy×cm), and total DLP in SECTPA examination was 77–245 mGy×cm

Table 1. Results summary of single-center study group examined with computed tomography pulmonary angiography (CTPA) at St. Michael's University Hospital Radiodiagnostic Clinic, Bratislava, Slovakia, 1 November 2018 – 31 December 2020

Method	Examinations (N = 105) [n (%)]	Initially examined patients (N = 92)		
		total [n (%)]	with confirmed PE (N = 22, 23.9%) [n]	without PE (N = 70, 76.1%)
DECTPA	67 (63.8)	59 (64.1)	11 (18.6% of initial DECTPA)	48 (81.4% of initial DECTPA)
SECTPA	38 (36.2)	33 (35.9)	11 (33.3% of initial SECTPA)	22 (66.7% of initial SECTPA)

DECTPA – dual-energy computed tomography pulmonary angiography, PE – pulmonary embolism, SECTPA – single-energy computed tomography pulmonary angiography.

Table 2. Clinical signs in suspicion of acute pulmonary embolism (PE) at St. Michael's University Hospital Radiodiagnostic Clinic, Bratislava, Slovakia, 1 November 2018 – 31 December 2020

Variable	Patients (N = 92) [n]	
	out of 81 patients[a]	out of 22 patients with acute PE
Deep vein thrombosis (DVT)	14	9
Dyspnea	47	14
Chest pain	19	8
Elevated D-dimer	63	18
All 4 clinical signs	4	4

[a] 11 patients with no data.

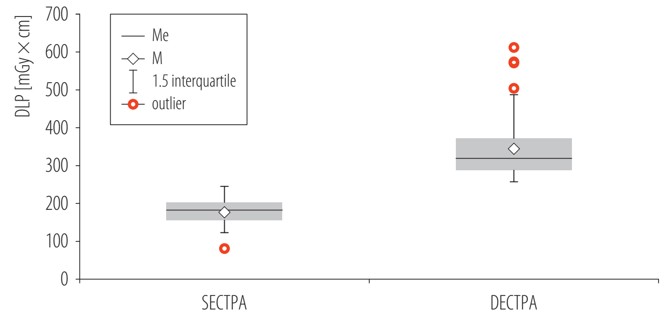

Figure 1. Dose-length product (DLP) of X-ray radiation exposure during the examination, depending on the chosen examination method at St. Michael's University Hospital Radiodiagnostic Clinic, Bratislava, Slovakia, 1 November 2018 – 31 December 2020

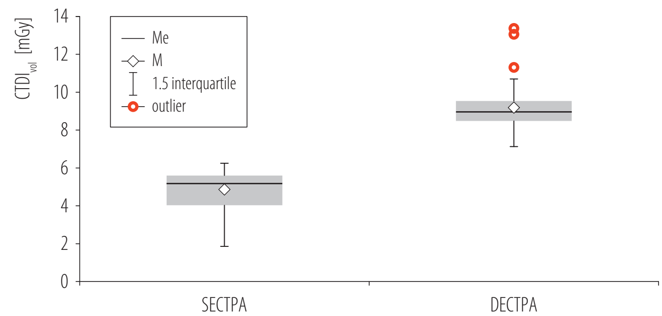

Figure 2. Volume computed tomography dose index ($CTDI_{vol}$) of X-ray radiation output from the scanner during the examination, depending on the chosen examination method at St. Michael's University Hospital Radiodiagnostic Clinic, Bratislava, Slovakia, 1 November 2018 – 31 December 2020

(M = 176.7 mGy×cm, Me = 182.5 mGy×cm) (Figure 1). The difference in DLP during DECTPA and SECTPA showed statistically significant ($p < 0.001$).

Volume computed tomography dose index in DECTPA examinations ranged 7.13–14.85 mGy (M = 9.19 mGy, Me = 8.96 mGy) and in SECTPA examinations ranged 1.86–6.25 mGy (M = 4.86 mGy, Me = 5.18 mGy) (Figure 2). The difference in $CTDI_{vol}$ during DECTPA and SECTPA also showed statistically significant ($p < 0.001$).

DISCUSSION

Computed tomography pulmonary angiography is the method of choice for diagnosing PE and is a crucial part of commonly used diagnostic algorithms. It is now readily available and has a high negative predictive value [2]. The use of modern multidetector CT devices has increased the sensitivity of CTPA by imaging small segmental or subsegmental PE, but the clinical significance of these small emboli is questionable, especially when it comes to isolated subsegmental pulmonary emboli [6–8]. In a retrospective review of isolated subsegmental embolization, Pena et al. [7] found that a small proportion of patients diagnosed with isolated subsegmental embolization (18 of 70 patients) did not receive any anticoagulation therapy, yet these patients did not develop recurrent venous thromboembolism (VTE), i.e., PE or DVT, during a 3-month follow-up. Therefore, undiagnosed isolated subsegmental embolization does not pose an immediate risk of recurrent VTE; on the contrary, patients may be at risk of overtreatment with bleeding complications [9,10].

The sensitivity of SECTPA and DECTPA in the assessment of lobar and segmental acute PE is the same [5], the advantage of DECTPA is the possibility to determinate the patency of the pulmonary vascular bed simultaneously with the pulmonary perfusion, which helps in the detection of small subsegmental pulmonary embolization and thus captures more PE than SECTPA allows. However, according to a study by Weidman et al. [3], the use of iodine perfusion maps helped to additionally detect acute PE in only 11 patients in a set of 1144 patients, representing 1.1%. In this single-center small cohort of patients examined for suspected PE, authors did not determine the number of cases in which DECTPA helped in the diagnosis of small subsegmental PE, but based on the results of a published study, the small benefit of iodine maps in the diagnosis of small acute subsegmental PE does not balance the fact that the radiation exposure in patients examined by DECTPA is almost double compared to SECTPA (the mean DLP in the cohort of patients in DECTPA was 344.4 mGy×cm, in SECTPA M = 176.7 mGy×cm, the ratio between the average DLP in DECTPA and SECTPA is 1.95), the max DLP in DECTPA was up to 2.5 times the max DLP in SECTPA (the max DLP in DECTPA was 612 mGy×cm, the max DLP in SECTPA was 245 mGy×cm, the ratio between the max DLP in DECTPA and SECTPA is 2.50). The same results were observed in $CTDI_{vol}$ values with mean $CTDI_{vol}$ value in DECTPA almost 2 times higher than mean $CTDI_{vol}$ value in SECTPA (M = 9.19 mGy vs. M = 4.86 mGy, respectively).

Based on the European Guidelines on Quality Criteria for CT from 2000, which are still valid, the DLP in chest CT is set at 650 mGy×cm [11]. In this cohort of patients the diagnostic reference level was not exceeded. The examination with the highest overall DLP was in DECTPA with 612 mGy×cm.

In this study acute PE was not confirmed in up to three-quarters of patients (76.1%) from this group of patients who were initially examined for suspected PE. Also, the clinical significance of the diagnosis of small acute subsegmental PE as an advantage of DECTPA remains questionable, especially if it concerns isolated subsegmental embolization that could remain untreated [7,12,13]. Considering the higher radiation exposure of DECTPA compared to SECTPA with their possible adverse stochastic effects on patients, in suspected acute PE the target should be a lower radiation exposure. The risk of adverse stochastic effects increases proportionally with the absorbed radiation dose and accumulates during the patient's life [14].

Findings of higher radiation exposure in DECTPA over SECTPA in this study conflict with the previously published research, showing that in phantom studies, there was no significant difference in radiation dose between DECT and conventional CT of the thorax [15,16]. Phantom studies compared dual-energy mode at 140 and 80 kVp and 140 and 100 kVp with single-energy CT at 120 kVp. In SECTPA examinations used for the study the voltage on the X-ray tube was lower – fixed at 100 kV, which improved the iodine contrast-to-noise ratio compared with 120 kV, and also reduced voltage on the X-ray tube during a single-source CT examination from 120 kVp to 100 kVp leads to a reduction of the radiation dose >30% [17,18].

The undoubted advantage of DECTPA with reconstructed perfusion iodine maps is not only the visualization of defects in the contrast filling of the lung parenchyma in acute PE, but also the visualization of defects in the contrast filling associated with chronic PE [4]. In the control examination after anticoagulant or thrombolytic treatment of acute PE, in the case of incompletely dissolved emboli in the peripheral pulmonary arteries, perfusion defects in the periphery of the lung parenchyma will be displayed. Subsegmental pulmonary arteries can also be closed by small clot remnants that can arise from the disruption of larger pulmonary emboli at the segmental or lobar level during anticoagulant treatment. In the chronic stage of PE, the pulmonary arteries are smaller, and the vessel lumen tends to be narrowed. These changes can be observed both on SECTPA and on DECTPA, but due to the narrowing of the vessels in the chronic stage, this detection is difficult only based on visual tracking of the vessels contrast filling in the periphery of the lung parenchyma at the subsegmental level. Defects in the subsegmental pulmonary arteries are very well revealed by the iodine perfusion map [19], which contributes to the follow-up of patients, and the possibility of monitoring the development of chronic subsegmental PE enables to detect of the early stages of possible chronic thromboembolic pulmonary hypertension (CTEPH) [20,21].

Limitations of this study are the small group of patients and voltage on the X-ray tubes set by the manufacturer to 100 and 140 kVp during the observed period of study, instead of 80 and 140 kVp used in other radiology departments [4,22]. Reducing the X-ray tube voltage leads directly to a reduction in the radiation exposure, and in the case of DECTPA with the advantage of enhancing of the contrast filling in the vessels. Therefore, at authors' Radiodiagnostic Clinic the input voltage on the X-ray tubes was already decreased to 80 kVp and 140 kVp, which contributed to the reduction of the radiation load in DECTPA.

Computed tomography scanner at authors' Radiodiagnostic Clinic undergoes regular quality controls provided by The Institute of Radiation Protection, Ltd. twice a year where among other things accuracy of $CTDI_{vol}$ and DLP is measured on a phantom. Therefore, the $CTDI_{vol}$ and DLP measured by the scanner reflect actual exposure.

CONCLUSIONS

Based on this study results, authors suggest using SECTPA instead of DECTPA in the diagnosis of acute PE to reduce the patient radiation exposure. The advantage of DECTPA is to monitor the PE evolution with the possibility of making iodine perfusion maps that help detect small chronic subsegmental PE and thus prevent chronic complications in the form of CTEPH, which, if untreated, is fatal.

AUTHOR CONTRIBUTIONS
Research concept: Martin Hazlinger, Zuzana Berecova
Research methodology: Martin Hazlinger, Zuzana Berecova, Viera Lehotska
Collecting material: Martin Hazlinger, Zuzana Berecova

Statistical analysis: Martin Hazlinger, Zuzana Berecova, Viera Lehotska
Interpretation of results: Martin Hazlinger, Zuzana Berecova, Viera Lehotska
References: Martin Hazlinger, Zuzana Berecova

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