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A Study of CT-derived Radiation Dose Calculation in Lung Q-SPECT/CT Imaging

Akciğer Q-SPECT/BT Görüntülemede BT Kaynaklı Radyasyon Doz Hesabı Çalışması

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Abstract

Objectives: To investigate the amount of effective dose (ED) due to the computed tomography (CT) component of lung perfusion-single-photon emission computed tomography (Q-SPECT)/CT.

Methods: In this single-center retrospective study, imaging data were collected from the clinic database for the period 2016-2022. The 327 patients identified were aged between 20 and 94 years. Tube voltage, tube current, pitch, gantry rotation time, volume CT dose index, and dose-length product (DLP) were recorded. The DLP was then converted to an ED using the conversion factors. The comparison of the ED between two groups was performed using the Mann-Whitney U non-parametric test.

Results: ED (mean ± standard deviation, mSv) was 1.20±0.70 for the pulmonary embolism (PE) (-) and 1.54±1.04 for the PE (+) cases ($p<0.05$). It was observed that there was a 28% increase in the ED for the PE (+) cases. In addition, each of the PE (-) and PE (+) cases was divided into two groups according to the use of the computed tomography dose reduction (CTDR): without CTDR protocol group (non-CTDR) and with CTDR protocol group (CTDR). For those groups, ED were obtained as 0.87±0.72 and 1.55±0.47 for PE (-) cases ($p<0.05$); 1.56±1.17 and 1.49±0.54 for PE (+) cases ($p>0.05$) correspondingly. For a deeper understanding, ED was calculated for all three groups formed with different tube voltage values applied for the non-CTDR and CTDR groups.There was a 42% decrease in the ED for group 1 PE (+) compared to group 2 PE (+) (1.21±0.28, 2.07±0.91, $p<0.05$) and there was a 41% decrease in the ED for group 1 PE (-) compared to group 2 PE (-) cases (1.17±0.32, 1.97±0.65, $p<0.05$).

Conclusion: It could be concluded that the effective DR protocol is the non-CTDR protocol for the PE (-) cases and the application of the tube voltage at the level of 100 kVp for the PE (+) cases.

Keywords: Lung Q-SPECT/CT, effective dose, dose reduction, pulmonary embolism

Öz

Amaç: Akciğer perfüzyon-tek foton emisyonlu bilgisayarlı tomografi/bilgisayarlı tomografinin (Q-SPECT/BT) BT komponenti kaynaklı maruz kalınan etkin doz (ED) miktarını araştırmaktır.

Yöntem: Bu tek merkezli ve retrospektif çalışmada, görüntüleme verileri 2016-2022 dönemi için klinik veri tabanından toplandı. Tanımlanan 327 hastanın yaşları 20 ile 94 arasındaydı. Tüp voltajı, tüp akımı, pitch, gantri rotasyon süresi, hacim BT doz indeksi ve doz-uzunluk çarpımı (DLP) kaydedildi. DLP daha sonra dönüştürme faktörleri kullanılarak ED'ye dönüştürüldü. İkili gruplar arasındaki ED karşılaştırması Mann-Whitney U non-parametrik test ile yapıldı.

Bulgular: ED (ortalama ± standart sapma, mSv) pulmoner emboli (PE) (-) olgular için 1,20±0,70 ve PE (+) olgular için 1,54±1,04 idi ($p<0,05$). PE (+) olgularda ED'de %28'lik bir artış olduğu gözlendi. Ayrıca, PE (-) ve PE (+) olguların her biri bilgisayarlı tomografi doz azaltımı (CTDR) kullanımına göre iki gruba ayrıldı: CTDR protokolü olmayan grup (non-CTDR) ve CTDR protokolü olan grup (CTDR). Bu gruplar için ED sırasıyla PE (-) olgular için 0,87±0,72 ve 1,55±0,47 ($p<0,05$); PE (+) olgular için 1,56±1,17 ve 1,49±0,54 ($p>0,05$) olarak elde edildi. Daha derin bir anlayış için ED, non-CTDR ve CTDR grupları için uygulanan farklı tüp voltaj değerleri ile oluşturulan üç grup için de hesaplandı. Grup 1 PE (+) için, grup 2 PE (+) ile

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karşılaştırıldığında ED'de %42 azalma (1,21±0,28, 2,07±0,91, p<0,05) ve grup 1 PE (-) için, grup 2 PE (-) ile karşılaştırıldığında ED'de %41 azalma (1,17±0,32, 1,97±0,65, p<0,05) vardı.

Sonuç: Etkin DR protokolünün PE (-) olgular için non-CTDR protokol ve PE (+) olgular için 100 kVp düzeyinde tüp voltajı uygulaması ile olduğu sonucuna varılabilir.

Anahtar kelimeler: Akciğer Q-SPECT/BT, etkin doz, doz azaltma, pulmoner emboli

Introduction

Single photon emission computed tomography/computed tomography (SPECT/CT) is recently preferred in nuclear medicine studies due to its superior features such as anatomical correlation and attenuation correction. SPECT/CT uses the body density map obtained from the CT scan and performs attenuation correction depending on the energy of the photon. Lung ventilation/perfusion (V/Q) scintigraphy or only perfusion single photon emission computed tomography/computed tomography (Q-SPECT/CT) is a widely used tool for the diagnosis of acute pulmonary embolism (PE) and for the follow-up of chronic PE because of its lower radiation doses with almost no contraindications (1).

Currently, an enhanced computed tomography pulmonary angiography (CTPA) study is recommended by the American College of Radiology as a primary diagnostic method for the detection of PE (2). However, V/Q SPECT is strongly recommended by the European Association of Nuclear Medicine as the first imaging choice for PE diagnosis (3). In the literature, a wide range for the effective dose (ED) of CTPA has been reported, which varies from 1.8 to 20 mSv, and the absorbed breast dose lies within the range of 2.8-70 mGy (4,5,6). The estimated ED range from V/Q SPECT is substantially lower, 0.6-3 mSv, and the absorbed breast dose is 1.1-1.5 mGy (6,7,8).

The best standard for the practice of imaging using ionizing radiation requires compliance with the As Low As Reasonably Achievable (ALARA) principle (9). Therefore, if CT is used for only attenuation correction and anatomical localization, low-dose CT should be preferred to avoid unnecessary radiation exposure. Low-dose CT is generally recommended in cases where concurrent diagnostic CT is available and in cases where treatment response is being evaluated. It is recommended that low-dose CT should be performed immediately after SPECT imaging. The amount of dose organ received in CT depends on many factors. The most important parameters are patient body mass index, slice thickness, number of slices, gantry rotation time, pitch value, tube voltage, and tube current value. Low-dose CT parameters may vary according to the technical specifications of the device. Dose reduction (DR) techniques are available in many systems. In addition, most of the CT acquisition parameters can also be changed by technicians during the CT examination (10).

There are a large number of studies in the literature that have attempted to determine the ED and absorbed breast dose for V/Q SPECT and CTPA studies (11). To the best of our knowledge, there is a single study reporting CT-derived ED in the Chronic Thromboembolic Pulmonary Hypertension (CTEPH) study group that underwent lung Q-SPECT/CT (12). However, we could not find any study using different CT parameters for DR in lung Q-SPECT/CT imaging. This study aimed to investigate the amount of radiation dose due to the CT component to which the patient is exposed during lung Q-SPECT/CT.

Materials and Methods

Study Population

The regional institutional Ondokuz Mayıs University Clinical Research Ethics Committee approved this retrospective study protocol (decision no: 2022/512, date: 23.11.2022). This single-center study was based on the data from lung V/Q-SPECT/CT imaging of patients under the suspicion of acute PE or chronic PE in follow-up using the Nuclear Medicine Department database. The final diagnosis was established with a composite reference standard that included electrocardiogram, ultrasound of lower extremity veins, D-dimer levels, CTPA, and clinical follow-up for at least 6 months. Imaging data from 2016 to 2022 were reviewed. All 327 patients were aged between 20 and 94 years and had undergone at least one lung Q-SPECT/CT imaging.

As of January 2022, a working system that is assumed to be more in line with the ALARA principles has been implemented. For CTDR protocol the rotation time applied to 132 cases was manually set as 0.66s, tube current as 120 mA, and pitch value as 1. Of these 132 cases, 61 patients received a tube voltage of 100 kVp (group 1) and 71 patients received a tube voltage of 120 kVp (group 2). The remaining 195 patients in the non-CTDR group received a rotation time of 1s, tube current of 160 mA, pitch value of 0.75, and tube voltage of 120 kVp (group 3). ED was then calculated for all three groups.

Acquisition Protocol

Five minutes after the intravenous injection of 200 MBq (5.4 mCi) of Tc-99m MAA in the supine position, acquisition started applying AnyScan® SC, combined SPECT gamma-camera and CT (Mediso Ltd., Budapest, Hungary) system. SPECT imaging specifications included an energy window of 140 keV 20%, single energy window scatter correction of 5% around the 120 keV peak, low energy high-resolution collimator, 128x128 matrix, 32 projections over 360°, and time per projection of 30 s for perfusion imaging. Low-dose CT scans of the chest were recorded during free breathing at 100-120 kVp and 80-160 mAs without intravenous contrast administration. Helical low-dose CT imaging of the thorax was acquired in dose modulation and the cephalocaudal direction, using settings of 0.66-1 s rotation time, helical thickness of 5 mm, pitch of 0.75-1, 512x512 matrix and collimation of 20x1.25. Q-SPECT images were reconstructed using ordered subset expectation maximization reconstruction, then fused with the corresponding CT image slices.

CT Dose Calculation

SPECT, CT, and fused images were interpreted simultaneously using InterView™ Fusion software (version: 3.08.008.0000; Mediso Ltd., Budapest, Hungary). This study was conducted using CT dose data from only Q-SPECT/CT images. Peak tube voltage (kVp), tube current (mA), pitch value, gantry rotation time, volume computed tomography dose index (CTDIvol), and dose-length product (DLP) were recorded for CT dose calculation. CT radiation dose assessment is performed by estimating the CTDIvol measured during a single rotation of the X-ray source. This index represents the absorbed dose along the longitudinal axis of the CT scanner. The unit of CTDIvol is mGy. To calculate the total absorbed dose in a full CT scan based on the scanned range (L) and the DLP was calculated as CTDIvolxL (mGy*cm) (13,14).

DLP was converted to an ED value using the conversion factor recommended by the ICRP publication 102 and AAPM report no. 96 (15,16). Therefore, a value of 0.014 was accepted as the conversion factor for the thoracic region and used throughout all ED analyzes corresponding to the results in Tables 1 and 2.

For the results in Table 3, note that the conversion factor for the male gender was taken as 0.0104 for the tube voltage of 100 kVp and 0.0105 for 120 kVp, and for the female gender was taken as 0.0183 for the tube voltage of 100 kVp and 0.0185 for 120 kVp, as reported in ICRP 103 (17).

TTo achieve the same image quality at a lower dose in this study, a dose modulation system was used. The CT scanner applied the tube current at a level appropriate to the patient's tissue attenuation.

Statistical Analysis

SPSS 22.0 software was used for statistical analysis of the data, which are presented as mean ± standard deviation (SD) and overall percentages. The non-parametric Mann-Whitney U test was used for CT-induced ED comparisons. A p-value of 0.05 was considered to indicate a statistically significant difference.

Results

One hundred thirty patients (40%, 86 female and 44 male) were diagnosed with PE. The embolism group consisted of acute and chronic cases. One hundred ninety-seven patients (60%, 109 female and 88 male) were diagnosed as negative for PE.

The data for the PE (-) and PE (+) cases are summarised in Table 1. ED (mean ± SD) was 1.20±0.7 mSv for the PE (-) cases and 1.54±1.04 mSv for the PE (+) cases, and there was a statistically significant difference between the ED of the PE (-) and PE (+) cases ($p<0.05$). It was observed that there was a 28% increase in the ED for the PE (+) cases. The measurements for non-CTDR and CTDR groups of PE (-) and PE (+) cases are summarized in Table 2. ED (mean± SD) was 0.87±0.72 mSv and 1.55±0.47 mSv for non-CTDR and CTDR groups of PE (-) cases ($p<0.05$); 1.56±1.17 mSv and 1.49±0.54 mSv for non-CTDR and CTDR groups of PE (+) cases ($p>0.05$), respectively. While the ED values presented similarity between the PE (+) non-CTDR and PE (+) CTDR groups, an increase in the ED was observed for the PE (-)

Table 1. CT parameters and calculated dose values in PE (-) and PE (+) cases

CT acquisition parameters and calculated dose values	Range	PE (-) (n=197) (mean ± SD)	PE (+) (n=130) (mean ± SD)
Peak tube voltage (kVp)	100-120	-	-
Tube current (mA)	120-160	-	-
Gantry rotation time (s)	0.66-1	-	-
Pitch value	0.75-1	-	-
CTDIvol (mGy)	1.21-13.65	3.1±1.7	4.5±3.1
DLP (mGy*cm)	9.49-399.46	85.8±49.7	110±74
ED (mSv)*	0.13-5.59	1.20±0.70	1.54±1.04

*p<0.05, DLP: Dose-length product, CTDIvol: Volume computed tomography dose index, ED: Effective dose, PE: Pulmonary embolism, SD: Standard deviation

CTDR group in comparison to the PE (-) non-CTDR group.

The measurements for groups 1-3 and the results of the pairwise ED comparison within the groups are shown in Table 3.

For pairwise comparisons between group 1 PE (-) and group 2 PE (-), group 1 PE (-) and group 3 PE (-), group 2 PE (-) and group 3 PE (-), and group 1 PE (+) and group 2 PE (+) cases, a statistically significant difference in ED was observed ($p<0.05$). However, no statistically significant difference ($p>0.05$) was observed between group 1 PE (+) and group 3 PE (+) and group 2 PE (+) and group 3 PE (+) cases (Table 3).

Noting the only difference between group 1 and group 2 that is the tube voltage of 100 kVp and 120 kVp, respectively, the analyzes regarding these two groups revealed that there was a 42% decrease in the ED in group 1 PE (+) compared to group 2 PE (+) cases (1.21±0.28 mSv, 2.07±0.91 mSv, $p<0.05$, respectively) and there was 41% decrease in the ED in group 1 PE (-) compared to group 2 PE (-) cases (1.17±0.32 mSv, 1.97±0.65 mSv, $p<0.05$, respectively).

Table 2. CT parameters and calculated ED results in the PE (-) and PE (+) cases with non-CTDR and CTDR protocol

CT acquisition parameters	PE (-) Non-CTDR (n=101)	PE (-) CTDR (n=96)	PE (+) Non-CTDR (n=94)	PE (+) CTDR (n=36)
Gantry rotation time (s)	1	0.66	1	0.66
Pitch value	0.75	1	0.75	1
Tube current (mA)	160	120	160	120
ED (mSv) (mean ± SD)	0.87±0.72	1.55±0.47	1.56±1.17	1.49±0.54
p-value (ED)	<0.05		>0.05	

Non-CTDR: Without CTDR protocol, CTDR: With CTDR protocol, ED: Effective dose, SD: Standard deviation

Discussion

In the examination and follow-up of pulmonary parenchymal lesions, it is now possible to perform a tomographic examination at doses close to the dose of chest radiography with low mAs values and other low-dose applications (18). Because a certain amount of noise can be tolerated in the detection of high-contrast lesions of the lung, mAs can be reduced. Low tube current-time product (mAs) images are especially useful for the examination of the lungs and paranasal sinuses, the investigation of urinary system stones, and CT-guided interventional procedures (19).

The dose varies linearly with gantry rotation time. A shorter gantry rotation time reduces the time the patient is exposed to radiation, thereby decreasing the dose and reducing the risk of motion artifacts. In most multislice computed tomography devices, the gantry rotation time is less than 1s. In our Q-SPECT/CT study, we applied two different values (0.66s and 1s) as the rotation time of the CT scanner. The pitch value is the ratio of the table advancement distance to the slice thickness in the complete rotation time of the tube. A high pitch factor reduces the dose by decreasing the X-ray exposure time of the examined area. However, this may negatively affect the image quality (20,21).

Tube voltage (kVp) determines the X-ray energy. It is a parameter that affects spatial and contrast resolution. The radiation dose is directly proportional to the square of the tube voltage. Therefore, small decreases in tube voltage significantly contribute to DR. In some examinations, this can be achieved by decreasing the tube voltage value without increasing noise and preserving image quality. Generally, tube voltage is used in the range of 70-140 kVp in clinical applications. Natural structures such as the lung, airway, and bone are high-density tissues that cause

Table 3. CT parameters and calculated ED results in the groups according to tube voltage

CT acquisition parameters	Group 1 CTDR 100 kVp		Group 2 CTDR 120 kVp		Group 3 Non-CTDR 120 kVp	
	PE (-) (n=44)	PE (+) (n=17)	PE (-) (n=52)	PE (+) (n=19)	PE (-) (n=101)	PE (+) (n=94)
Gantry rotation time (s)	0.66	0.66	0.66	0.66	1	1
Pitch value	1	1	1	1	0.75	0.75
Tube current (mA)	120	120	120	120	160	160
ED (mSv) (mean ± SD)	1.17±0.32	1.21±0.28	1.97±0.65	2.07±0.91	0.91±0.8	1.84±1.48
p-value (ED)	>0.05		>0.05		<0.05	

Non-CTDR: Without CTDR protocol, CTDR: With CTDR protocol, ED: Effective dose, SD: Standard deviation, PE: Pulmonary embolism, CT: Computed tomography

natural contrasts. Therefore, a low tube voltage in the range of 80-100 kVp can be applied more safely in the examination of these structures (20,21). In our study, the ED at tube voltages of 100 and 120 kVp was investigated in accordance with the values reported in the literature.

The tube current (mA) is related to the number of X-rays produced by the tube. Multiplying this with the gantry rotation time gives mAs. The radiation dose is directly proportional to the change in the tube current. However, careless and unplanned irradiation may lead to decreased image quality as a result of increased noise (20,22). In a Q-SPECT/CT study conducted with values of CT irradiation parameters, similar to our study (120 kVp, 1s gantry rotation time, 1.25 pitch), it was reported that embolism diagnostic accuracy was 94.9%, with a sensitivity of 98.6%, and specificity of 94.5% even at 30 mAs (23).

With the developing technology in CT devices, the optimum kVp and mAs values are calculated according to the region of the patient that can be examined in the contrast-to-noise ratio, especially in the first topogram images, and it is aimed to provide optimum image quality at low radiation dose. There are also studies indicating that automatic tube voltage selection provides more radiation DR than other methods (24). However, by creating group 1 (100 kVp) and group 2 (120 kVp) with manual selection of tube voltage in our study also revealed that a 41% reduction in ED can be achieved in group 1 PE (-) and a 42% reduction in group 1 PE (+) cases.

Referring to an embolism study (25) that applied the same DR as ours, we also do not expect a difference in sensitivity and specificity values to achieve adequate image quality. In a study the tube voltage value of 80 kVp used for CTPA in patients weighing less than 100 kg resulted in a 40% DR, compared to 100 kVp without deterioration in image quality (26).

While the average ED in a standard thorax CT is approximately 6 mSv, this value is approximately 1.6 mSv in low-dose thorax CT. In the literature, it has been reported that the tube current used in low-dose CT is less than 100 mAs and the tube voltage is usually 120 kVp (27,28,29). Roach et al. (28) showed that CT scans for chest/abdomen anatomical localization amount to up to 1-2 mSv.

It is thought that the unexpected increase in ED despite the lower value of the gantry rotation time and tube current and the higher value of the pitch in the CTDR studies may be due to the activation of the dose modulation system. CT parameters such as tube current, gantry rotation time, tube voltage, and pitch value are the factors that affect the radiation dose. If one of these parameters is changed, the dose modulation may increase the tube current to ensure adequate image quality (30). Decreasing the gantry rotation time may be compensated by an increase in mAs to maintain the mAs at a constant level (31). In our study, an increase in ED was observed in the group 2 PE (+), group 2 PE (-), and group 1 PE (-) cases, which may be caused by such compensations (Table 3).

In a Q-SPECT/CT study (12), CT was performed with a pitch value of 1.25, rotation time of 1s, tube current-time product of 30 mAs, and tube voltage of 120 kVp. Then, the ED (mean ± SD) was computed as 2.1±0.62 mSv (12), which is similar to the results obtained from group 2 in our study.

No statistically significant difference in ED was observed in the PE (+) cases with CTDR group compared to the non-CTDR group, whereas an increase in ED was observed in the PE (-) cases with CTDR group ($p<0.05$). In the group comparisons of PE (+) cases, effective DR was observed only in group 1 PE (+) cases with 100 kVp tube voltage compared to group 2 PE (+) cases with 120 kVp tube voltage ($p<0.05$) (Table 3). In addition, group 3 PE (-) has the lowest ED of all the groups considered. All these findings indicate that the best DR protocol for the PE (-) cases can be considered as a non-CTDR protocol and for the PE (+) cases, the application of tube voltage at the 100 kVp level. Regarding image acquisition protocols, it has been reported that nuclear medicine specialists should adjust the CT imaging procedure by considering the patient's clinical data (32). Lung Q-SPECT/CT is a hybrid application in which SPECT images are first obtained, followed by CT images. Therefore, in Q-SPECT/CT imaging, after the specialist comments on the possibility of PE from the SPECT image, a reduction in ED can be achieved in accordance with the ALARA principle. If the patient shows perfusion defect(s) in SPECT images, the application of tube voltage at 100 kvp level could be used. However, if the patient has no perfusion defect, the non-CTDR protocol should be preferred.

In our study, by applying 80 and 160 mAs and tube voltages of 100-120 kVp, ED (mean ± SD) were calculated as 1.20±0.70 mSv and 1.54±1.04 mSv for the PE (-) and PE (+) cases, respectively. It was observed that ED in the PE (+) was higher than that in the PE (-) cases. PE is a clinical condition that causes many histopathological changes in the lung parenchyma and bronchovascular system. In a recent study that compared pulmonary vascular resistance (PVR) and mean pulmonary arterial pressure (mPAP) values with a CT scoring system that included main pulmonary artery diameter and mosaic perfusion pattern, a highly significant statistical correlation was observed between the CT scoring and both mPAP and PVR ($p<0.05$). High

PVR and mPAP have been reported as a consequence of hemodynamic changes in the lung due to CTEPH (33). In another study, vascular attenuation was calculated using region of interest drawn on the main pulmonary arteries and their peripheral branches, and increased attenuation was found in both acute and chronic PE [33 Hounsfield unit (HU) for acute PE, 87 HU for chronic PE]. Similarly in our study, there were acute and chronic cases in the embolism positive group. It could be thought that the difference in tissue attenuation caused a statistically significant increase in ED in the embolism-positive group compared with the embolism-negative group (34). New studies are required to support this idea.

Study Limitations

Because our study was retrospective, the body mass index of the patients could not be included in the evaluation.

A subgroup evaluation using different voltage levels in the non-CTDR group would have added a new perspective to this study. However, in our study, only single voltage results were available in the non-CTDR group. Investigating this issue in future studies may allow for more objective evaluations.

Conclusion

As a result, it is concluded that reducing the tube voltage level alone rather than CTDR protocol might be sufficient to achieve an ED decrease in PE (+) patients.

Ethics

Ethics Committee Approval: The regional institutional Ondokuz Mayıs University Clinical Research Ethics Committee approved this retrospective study protocol (decision no: 2022/512, date: 23.11.2022).

Informed Consent: Data for this retrospective study were obtained from the medical records of the hospital, and patient consent was waived by the approval of the Institutional Review Board.

Peer-review: Externally and internally peer-reviewed.

Authorship Contributions

Surgical and Medical Practices: G.S., F.B., Concept: G.S., Design: G.S., Data Collection or Processing: F.B., Analysis or Interpretation: G.S., Literature Search: G.S., F.B., Writing: G.S., F.B.

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