Original Article
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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

Short Title in English: Radiation Dose Calculation Q-SPECT/CT

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ABSTRACT
INTRODUCTION: To investigate the amount of effective dose (ED) due to the CT component of lung Q - SPECT/CT.
METHODS: In this single-center and retrospective study, the 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 computed tomography dose index (CTDIvol) and dose-length product (DLP) were recorded. DLP was then converted to an ED using the conversion factors. The comparison of the ED between two groups was performed by means of the Mann-Whitney U non-parametric test.
RESULTS: ED (mean±SD, mSv) were 1.20±0.70 for the pulmonary embolism (PE) (-) group and 1.54±1.04 for the PE (+) group (p<0.05). It was observed that there was a 28% increase in the ED for PE (+) group. By the appliance of CT dose reduction (DR), the cases were divided as nonCTDR and CTDR groups. For those, 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 also calculated for three groups created by different values of the tube voltage applied for both nonCTDR and CTDR. 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 (-) in comparison to Group 2 PE (-) (1.17±0.32, 1.97±0.65, p<0.05) respectively.
DISCUSSION AND CONCLUSION: It could be concluded that the effective DR protocol is the nonCTDR application for the PE (-) group and the application of tube voltage at 100 kVp level for the PE (+) group.
Keywords: Lung Q SPECT/CT, Effective Dose, Dose Reduction, Pulmonary Embolism

ÖZ
GİRİŞ ve AMAÇ: Akciğer Q-SPECT/BT'nin BT komponenti kaynaklı maruz kalınan etkin doz (ED) miktarını araştırmak.
YÖNTEM ve GEREÇLER: 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 bilgisayarlı tomografi doz indeksi (CTDIvol) 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±SD, mSv) pulmoner emboli (PE) (-) grup için 1.20±0.70 ve PE (+) grup için 1.54±1.04 idi (p<0.05). PE (+) grup için ED'de %28'lik bir artış olduğu gözlendi. BT doz azaltımı uygulamasına göre olgular BT doz azaltımı yapılmayan (nonCTDR) ve BT doz azaltımı yapılan (CTDR) gruplar olarak ayrıldı.

Bu gruplar için ED PE (-) olgular için sırasıyla 0.87±0.72 ve 1.55±0.47 (p<0.05); ve benzer şekilde PE (+) olgular için sırasıyla 1.56±1.17 ve 1.49±0.54 (p>0.05) olarak elde edildi. Daha derin bir anlayış için ED, hem nonCTDR hem de CTDR için uygulanan tüp voltajının farklı değerleriyle oluşturulan üç grup için yeniden hesaplandı. Grup 2 PE (+) ile karşılaştırıldığında Grup 1 PE (+) için ED'de %42 azalma (1.21±0.28, 2.07±0.91, p<0.05) ve Grup 2 PE (-) ile karşılaştırıldığında Grup 1 PE (-) için ED'de %41 azalma (1.17±0.32, 1.97±0.65, p<0.05 vardı.
TARTIŞMA ve SONUÇ: Etkin doz azaltma protokolünün PE (-) grubu için nonCTDR protokol ile, PE (+) grubu için 100 kVp seviyesinde tüp voltajı uygulaması ile olabileceği 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 also for the follow-up of chronic PE due to their 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 (ACR) 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 (EANM) as the first imaging choice for PE diagnosis (3). In the literature, a wide range for the effective dose (ED) of CTPA is 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 ALARA (As Low As Reasonably Achievable) 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 also in cases where treatment response is being evaluated. It is recommended that low-dose CT scanning should be performed immediately after SPECT imaging. The amount of dose organ received in CT depends on many factors. The most important of those 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 accordingly to the technical specifications of the used device. Dose reduction (DR) techniques are available in many systems. Additionally, most of the CT acquisition parameters can also be changed by technicians during the CT examination (10).

In the literature, there appear many studies to determine the ED and absorbed breast dose in lung V/Q SPECT and CTPA studies (11). To the best of our knowledge, there is a single study reporting CT-derived ED for the Chronic Thromboembolic Pulmonary Hypertension (CTEPH) study group that underwent lung Q-SPECT/CT (12). But, we could not find any study using different CT parameters for the purpose of 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 VE METHODS

Study population

The regional institutional ethics committee approved the present retrospective study protocol (2022000512/ 30th November 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 ECG, 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 20-94 and had undergone at least one lung Q-SPECT/CT examination.

As of January 2022, a working system that is assumed to be more in line with the ALARA principles has been implemented. For CT dose reduction (CTDR) purposes, the rotation time applied to 132 cases was manually set as 0.66s, tube current as 120 mA, and pitch value as 1. Of those 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 within nonCTDR received a rotation time of 1s, tube current of 160 mA, pitch value of 0.75 along with tube voltage of 120 kVp (Group 3). Then, ED was 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 the 30s 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 detector configuration of 16x1.25. Q-SPECT images were reconstructed utilizing 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™ XP software (version: 3.06.007.0001; 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 CTDIvol x L (mGy*cm) (13, 14).

DLP was converted to 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 thorax region and used throughout all analyses of ED corresponding to the results of Table 1 and Table 2.

For the results of 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).

To achieve the same image quality at a low dose in this study, a dose modulation system was used in which the CT scanner applies the tube current in an appropriate amount to the tissue attenuation of the patient.

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 less than 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 consists of both 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 summarized in Table 1. ED (mean±SD) was 1.20±0.7 mSv for the PE (-) group and 1.54±1.04 mSv for the PE (+) group, and there was a statistically significant difference between the ED of PE (-) and PE (+) patient groups ($p<0.05$). It was observed that there was a 28% increase in the ED for PE (+) group.

The measurements for the PE (-) and PE (+) with nonCTDR and CTDR cases are summarized in Table 2. ED (mean±SD) was 0.87±0.72 mSv and 1.55±0.47 mSv for PE (-) cases of nonCTDR and CTDR ($p<0.05$); 1.56±1.17 mSv and 1.49±0.54 mSv for PE (+) cases of nonCTDR and CTDR ($p>0.05$), respectively. While the ED values presented similarity between PE (+) nonCTDR and PE (+) CTDR groups, an increase in the ED was observed for the PE (-) CTDR in comparison to PE(-) nonCTDR group.

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

While a statistically significant difference in effective doses was observed in pairwise comparisons between Group 1 PE (-) and Group 2 PE (-), Group 1 PE (-) and Group 3 PE (-), Group 2 PE (-) and Group 3 PE (-), Group 1 PE (+) and Group 2 PE (+) ($p<0.05$) respectively, no statistically significant difference was observed between Group 1 PE (+) and Group 3 PE (+), and Group 2 PE (+) and Group 3 PE (+) ($p>0.05$) (Table 3).

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

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). Since 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) of 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 the gantry rotation time. A shorter gantry rotation time reduces the time the patient is exposed to the radiation, thereby decreasing the dose and reducing the risk of motion artifacts. In most multislice computed tomography (MDCT) 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 a 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 badly affect the image quality (20, 21).

Tube voltage (kVp) determines the X-ray energy. It is a parameter affecting spatial and contrast resolution. The radiation dose is directly proportional to the square of the tube voltage. Therefore, small decreases in tube voltage contribute significantly to dose reduction. 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 and cause natural contrasts. Therefore, 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 kVp and 120 kVp was investigated in accordance with the values in the literature.

The tube current (mA) is related to the amount of X-rays produced from the tube. Multiplying this with the gantry rotation time gives the mAs. The radiation dose is directly proportional to the change in tube current. However, careless and unplanned irradiation may lead to a decreased image quality as a result of increasing noise (20, 22). In a Q-SPECT/CT study conducted with the values of CT irradiation parameters similar to our study (120 kVp, 1s gantry rotation time, 1.25 pitch) in the literature, 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 (CNR), 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 compared to other methods (24). However, manual selection of tube voltage creating Group 1 (100 kVp) and Group 2 (120 kVp) as in our study also revealed that a 41% reduction in ED can be achieved in the Group 1 PE (-) and a 42% reduction in the Group 1 PE (+). Referring to an embolism study (25) that applied the same dose reduction as ours, we also do not expect a difference in sensitivity and specificity values to achieve adequate image quality. In a study, the value of 80 kVp used for CTPA in patients weighing less than 100 kg resulted in a 40% reduction in radiation exposure 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, 29). Roach et al. showed that CT scans for chest/abdomen anatomical localization amount up to 1–2 mSv (28). In our study, by applying 80 and 160 mAs and tube voltage of 100-120 kVp, ED (mean±SD) were calculated as 1.20±0.70 mSv and 1.54±1.04 mSv for PE (-) and PE (+) groups, respectively. It was observed that ED in the PE (+) patient group was higher than in the PE (-) patient group.

It is thought that the unexpected increase in ED despite of 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, tube rotation time, tube voltage, and pitch value are 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 the 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.

When compared with the nonCTDR group, no statistically significant change in ED was observed in PE (+) groups with CTDR application, whereas an increase in ED was observed in PE (-) groups with CTDR application ($p<0.05$). In PE (+) group comparisons, effective DR could be observed only in Group 1 PE (+) (100 kVp) group compared to Group 2 PE (+) (120 kVp) ($p<0.05$) (Table 3). Besides, PE (-) Group 3 has the lowest ED amongst all groups considered. All these findings point out that the best DR protocol for the PE (-) cases can be considered as nonCTDR protocol and for the PE (+) cases the application of tube voltage at 100 kVp level.

Regarding image acquisition protocols, it has been reported that nuclear medicine specialists should adjust the CT imaging procedure by taking into account the patient's clinical data (32). Lung Q-SPECT/CT is a hybrid application in which firstly SPECT images are obtained, followed by CT images. Therefore, in a Q-SPECT/CT imaging, after the specialist comments on the possibility of PE from the SPECT image, a reduction in the 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. But if the patient has no perfusion defect, the nonCTDR protocol should be preferred.

Pulmonary embolism is a clinical condition that cause to many histopathologic changes in the lung parenchyma and broncho-vascular 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 (MPA) 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 ROIs drawn on the main pulmonary arteries and their peripheral branches, and increased attenuation was found in both acute and chronic PE (33 HU for acute PE, 87 HU for chronic PE). Similarly in our study, the embolism positive group consisted of both acute and chronic cases. It could be thought that the difference in tissue attenuation caused a statistically significant increase in the ED in the embolism positive group compared to the embolism negative group (34). New studies are needed to support this idea.

Limitations of the study

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

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

Conclusion

As a result, it is concluded that reducing kVp alone rather than CTDR application might be enough to achieve an ED decrease for PE (+) patients.

Acknowledgment/Disclaimers/Conflict of interest

There is no funding for this research. All authors declare that they have no conflicts of interest.

Informed consent

Data of 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.

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Table1. The applied CT parameters and calculated ED results in PE (-) and PE (+) groups.

CT Acquisition Parameters and Radiation 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	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

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

CT Acquisition Parameters	PE (-) nonCTDR (N=101)	PE (-) CTDR (N=96)	PE (+) nonCTDR (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	

nonCTDR; The parameters of CT with original software-tuned, CTDR; The parameters of CT for purpose of dose reduction, ED; Effective dose

Table 3. CT dose 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 nonCTDR 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

nonCTDR; The parameters of CT with original software-tuned, CTDR; The parameters of CT for purpose of dose reduction, ED;Effective dose