بسم الله الرحمن الرحيم
Ahvaz Jondishapur University of Medical Sciences
Faculty of Medicine

Thesis for Medical Specialist degree
Title: Comparison of image quality of low voltage CT angiography (80 kilovoltage) with standard condition (100 kilovoltage) in patients suspicious to pulmonary emboli

Supervisor(s):
Dr Mohammad Davoodi

Author:
Soudabeh Belash Abadi

Registration No:
ی/659

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دانشکده پزشکی
فرم صورتجلسه دفاع از پایان نامه

با تأییدات خداوند متعال جلسه دفاع از پایان نامه خانم آقای دکتر باقری رشتی را برگزاری کرد به شماره دانشجویی ۱۲۳۴۵۶۷۸ در مبحث .. مقطع .. با حضور استادان راهنما، مشاور و هیأت داوران در محل .. با شماره ثبت .. ۱۲۳۴۵۶۷۸۹ در تاریخ .. .. تشکیل و با موافقت از پایان نامه خود دفاع نموده و موفق به کسب نمره .. آماده .. (به حروف اشراقی نوشته) با رتبه .. .. گردیده است.

استاد (ان) راهنما: دکتر محمد رضا رضوی

استاد (ان) مشاور:

هیأت داوران:

۱- دکتر مفتح علمایی
۲- دکتر حسین چمران
۳- دکتر احمد سلیمی

مدیر گروه: دکتر کریم زاده

معاون پژوهشی دانشکده پزشکی:
Abstract

Background: Reduction of peak kilovoltage (KV) setting has been found as an effective approach to decrease radiation does but may has different effects on noise and accuracy of the diagnosis. We aimed to compare quality of images at 80 KV versus 100 KV, providing an evidence for safe and effective imaging approach.

Methods: In a phase one diagnostic non-randomized triple blind parallel quasi-experimental study we evaluated 140 suspicious cases of pulmonary emboli either by 80 or 100 KV CT angiography. Primary outcome measure was number of measurable arteries in different segments of lungs, pulmonary vascular enhancement, image noise and image quality score.

Results: Age, gender, weight, height, BMI, job, smoking habits and concomitant diseases were similar between two groups but pulmonary emboli (PE) was more frequent (P=0.031) and chest cross-section area was higher (P=0.013) in 100 kilovoltage group. Quality of images was better in 80 KV group (OR, 95% CI: 2.08, 1.74-2.47). Vascular enhancement was significantly higher in all main, segmental and subsegmental arteries (P< 0.001 in all) in 80 KV group as well. Mean number of measurable segmental arteries was also significantly higher among voltage 80 group. On the other hand, mean of image noise was higher (68.4 vs. 43.1) among images with 80 KV (P-value < 0.001). Received radiation dosage in group with 80 KV and 100 KV were 0.94 and 2.43 mSv (P < 0.001).

Conclusion: Despite worse image noise, received radiation dosage was lower and image quality was better in cases with 80 KV in comparison with 100 KV.

Key words: Image Enhancement; image quality; CT angiography; Pulmonary Embolism
List

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Chapter One

Problem statement

and Literature Review
**Problem statement**

In recent years, spiral computed tomography (CT) has been established as the method of choice for diagnosing acute pulmonary embolism (PE). For central pulmonary arteries down to the segmental level, single-detector CT was found to provide a sensitivity and specificity ranging between 80% and 90% (1–3). The major disadvantage of single-detector CT, however, was its inability to reliably depict peripheral emboli (4). This limitation has been largely overcome by the introduction of multidetector CT systems (3,5). Radiation exposure, however, may increase substantially with the use of multidetector scanning, especially when newer multidetector scanners are compared with the last generation of single-detector scanners (6,7). Radiation risk becomes especially important in patients with non–life-threatening PE, in patients with a low clinical probability of PE, and in young individuals, particularly female patients, who may be exposed to substantial levels of radiation to their breasts during CT (8). The importance will increase specifically when we know that prevalence of PE in cases undergoing CT angiography is lower than 10% (9-10).

Low kilovoltage scanning has been suggested as a technique to improve contrast enhancement, as well as a technique for radiation dose reduction (11–14). This technique has been applied in angiography and better matches the effective energy of the x-ray beam to the maximum absorption close to the k-edge of iodine. Low kilovoltage techniques substantially increase the relative attenuation (in CT numbers) of contrast material and, thus, vascular enhancement at CT. At the same time, the absolute amount of x-ray attenuation grows as well. As a consequence, in-
creasing body size will disproportionately increase image noise with low kilovoltage techniques compared with high kilovoltage techniques. This is a substantial problem in the abdomen but—because of less-attenuating tissue—much less of a problem in the lungs. The chest is therefore an anatomic region that should be well suited for the use of low kilovoltage techniques.

CT angiography of the pulmonary arteries appears to represent an appropriate model system for the evaluation of low kilovoltage techniques because of a well-circumscribed primary imaging task (detection of PE) and the fact that suboptimum enhancement of the pulmonary arteries directly affects image evaluation. Image quality can be relatively easily quantified by assessing the ability to evaluate small pulmonary arteries. Compared with multidetector CT, single-detector CT suffers much more from partial volume effects that decrease the apparent attenuation of small vessels and make reliable evaluation of small or peripheral vessels much more difficult. In these conditions, low kilovoltage techniques should be particularly advantageous.

The increase in vascular attenuation (signal) at low kilovoltage settings should allow an appropriate increase in image noise without affecting the signal-to-noise ratio compared with higher kilovoltage settings. This should offer the potential for dose reduction with low kilovoltage techniques.

Low voltage CT scan, mostly has been used for other diseases in other parts of the body like cerebrovascular (15) and lung (16) blood flow. However, in this study we are persuading novel application with different voltage in comparison with relatively similar studies. The most similar study about lung diseases has been compared 100 and 140 kilovoltage (16).
The cause of selecting a lower voltage in present study is previous studies which believe vascular enhancement increases when we decrease the radiation dose (15-19). The purpose of this study was to prospectively compare a low kilovoltage scanning protocol with a reduced radiation dose with a standard high kilovoltage, moderate-dose protocol for the depiction of central and peripheral pulmonary arteries at multiple-detector spiral CT.

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**Literature Review**

**Acute Pulmonary Embolism**

Imaging plays a crucial role in the diagnosis of pulmonary embolism (PE) and deep venous thrombosis (DVT), a spectrum of the same disease entity. PE is the third most common cause of cardiovascular death in the United States, following ischemic heart disease and stroke, with an annual incidence of 300,000 to 600,000 per year.(20-21) Despite the high prevalence, PE is difficult to diagnose, with only 43 to 53 patients per 100,000 being accurately diagnosed, and up to 70% of clinically unsuspected PE diagnosed at
In the past few decades, the incidence of PE has decreased by 45%, whereas that of DVT is unchanged. Death occurs in up to 90% of patients with unrecognized PE, whereas in treated patients PE accounts for less than 10% of deaths.

Rapid and timely diagnosis of this life-threatening disease is important to improve patient outcome as the signs and symptoms as well as ancillary tests are nonspecific. The recent rapid growth in CT technology over the past decade has seen the emergence of CT pulmonary angiography (CTPA) as the single first line test in the diagnosis of PE because of its high diagnostic accuracy and ability to provide alternate diagnosis for diseases of the lung parenchyma, pleura, pericardium, aorta, heart, thoracic lymph nodes, and mediastinum.

The widespread availability and use of CTPA has made the diagnosis of PE easier in most cases, but has raised the need for optimal use of this technique in the appropriate patient population, in order to minimize unnecessary medical radiation exposure.

Pretest risk stratification using Wells criteria, clinical probability scores, assessing premorbid conditions, past history, and a thorough clinical examination should precede an appropriate, timely, and accurate diagnostic test. In some common scenarios like pregnancy and in critically ill patients, the diagnosis of PE still remains challenging.
**DIAGNOSIS OF ACUTE PULMONARY EMBOLISM**  
Ventilation-Perfusion Scintigraphy

Combined ventilation and perfusion (V/Q) scintigraphy had been the imaging technique of choice for decades. A V/Q scan with normal findings essentially excludes pulmonary embolism with an NPV (Negative Predictive Value) close to 100%, thereby precluding the use of anticoagulation, whereas a high-probability scan is highly specific for the diagnosis of PE, allowing definitive treatment. In the original PIOPED (Prospective Investigation of Pulmonary Embolism Diagnosis) study only 14% of patients had a normal V/Q scan and 13% a high-probability V/Q scan, rendering a definitive diagnosis in only a small group of patients; most (73%) had an indeterminate (non-diagnostic) or low-probability test result. (29) This high degree of uncertainty makes initiation of definitive anticoagulant therapy difficult because of risk of bleeding and necessitates additional tests to diagnose or exclude pulmonary embolism. The criteria for reporting V/Q scans have improved significantly. (30) Recent use of V/Q scanning with SPECT allows 3-dimensional visualization of segments previously not identified on planar imaging, such as the medial basal segment of the right lower lobe. The lung segments are more clearly defined and can be viewed in any orthogonal plane, resulting in better detection and characterization of
defects.(31) SPECT also improves image contrast, thus decreasing the rate of intermediate scan reports. Large-scale trials are needed to fully assess this modality and compare its performance with CTPA. Currently the definitive primary role of V/Q scanning is in patients where CTPA is contraindicated as in severe renal impairment or history of iodine or contrast allergy.

**Catheter Pulmonary Angiography**

Catheter pulmonary angiography has been considered as the reference test for the diagnosis of PE since the late 1960s. However, the invasive nature and expense of the study along with a small but definite risk in morbidity has contributed to its underutilization. Two studies, done 12 years apart in 1240 patients, showed that following an inconclusive V/Q scan result, catheter pulmonary angiography was performed in less than 15% of patients.(32-33) Many patients were treated with anticoagulants without a definitive result. Accurate diagnosis is important, as anticoagulants themselves account for significant morbidity (up to 6.5%), that increases with age and with comorbid conditions.(34-35)

With the newer generation of MDCT (multidetector CT) scanners, the role of catheter pulmonary angiography as the gold standard test has been questioned and is considered to be flawed, particularly at the subsegmental level.(36-37) The interobserver agreement at the subsegmental level on the original PIOPED
study was reported to be only 66%.

(29) In PIOPED II, in the 20 discordant cases, PE was missed at the lobar, segmental, and subsegmental levels in 13 patients; 8 of 13 were at the subsegmental level. (38) The current role of catheter pulmonary angiography is when CTPA is inconclusive, or when the clinical findings are discordant with CTPA results.

**CT Pulmonary Angiography**

Incidental detection of PE was first documented by Sinner in 1978. (39) The advent of single-detector helical CT in the early 1990s, made it possible to obtain volumetric datasets with good contrast in a single breath-hold, allowing diagnosis predominantly of central and segmental PE. With rapid evolvement of CT technology, the CT diagnosis of PE has been a subject of much research in the past couple of decades, and has resulted in CTPA becoming a first-line imaging test at many centers. (40) CTPA is a relatively safe, accurate, readily available and cost-effective noninvasive test that not only diagnoses PE, but also provides diagnosis of alternative pathologies in the thorax accounting for patient symptoms, particularly in the inpatient and emergency department settings. Faster multidetector scanners have set the way for a potential new gold standard test. With newer 128 and higher slice scanners, the sensitivity and specificity is likely to increase albeit at a cost of increased radiation.
Advances in MDCT

MDCT has several advantages over SDCT (single detector CT) in the diagnosis of PE, which include improved z-axis resolution, shorter scan times, reduction in volume of contrast, and the ability to do a combined CTPA/CT venography (CTV) exam at the same setting with a single bolus of contrast.

Z-Axis Resolution

Advances in MDCT technology with improved gantry rotation speeds and increased detector width allow rapid acquisition of large volumetric datasets over a greater craniocaudal distance than with SDCT. While reduction in slice collimation with SDCT results in a longer breath hold and a likelihood of increased respiratory motion artifact, with MDCT reduction in slice thickness leads to better visualization of subsegmental pulmonary arteries, with 94% of fifth order and 74% of sixth order pulmonary arteries being visualized.(41-43) Reducing the reconstruction thickness decreases partial volume averaging and also results in better visualization of the obliquely oriented middle lobe and lingular arteries, in which an estimated 20% of emboli occur.(36) Reducing the slice thickness also improves the interobserver agreement for diagnosis of PE.(44)

Shorter Scan Acquisition Time
A shorter breath hold translates into decreased respiratory motion artifact which in turn results in less indeterminate studies and allows better visualization of the subsegmental pulmonary arteries. The scan range for SDCT typically ranges from 15 to 20 cm from the top of the aortic arch to the dome of the diaphragm, with a breath hold of 30 to 40 seconds or longer, whereas the entire chest can be scanned with 16-slice or higher generation MDCT scanners at a shorter breath hold of 3 to 10 seconds.

**Decrease in Contrast Volume**

The shorter acquisition time enables a reduction in volume and tighter bolus of contrast for optimal opacification of the pulmonary arteries. With SDCT and early generation MDCT, contrast volumes of 120 mL or higher were commonly used, whereas on the current generation of MDCT scanners, studies can be performed with doses of 80 mL or less. A saline chase can also be used to further reduce the volume of contrast and to decrease beam hardening artifact from the SVC as is done for imaging of the coronary arteries.

**CT Pulmonary Angiography Technique**

With rapidly advancing MDCT technology, the techniques and protocols are continually evolving. Precise techniques vary between the different generation of
scanners and between vendors. **Table 1** suggests parameters for CTPA using different generations of MDCT scanners. The imaging acquisition on the current generation of scanners includes the entire lungs with resolution of 1.25 mm or less. The aim is to perform the study at thinnest slice collimation with a single short breath hold in full suspended respiration. With the 64-slice and higher generation scanners, it is possible to obtain the entire study with a breath hold of less than 5 seconds. In intubated patients, because of the short acquisition time, respiration can be suspended for the duration of the study. With such short breath holds, it does not matter whether the scan is acquired in a caudocranial or craniocaudal direction.

Power injectors are required for rapid contrast delivery to obtain adequate enhancement of the pulmonary arteries. An 18- to 20-gauge intravenous cannula is placed in the antecubital vein. The degree and quality of pulmonary arterial enhancement depends on the amount and concentration of contrast, injection rate, and the scan delay. On the 64-slice scanner we use 70 mL of contrast (Iovue 370, Bracco Diagnostics, New Jersey) for CTPA imaging of the chest alone, and for a combined CTPA/CTV study we use 120 mL of contrast (Iovue 370 Bracco Diagnostics) at 4 mL/s. A greater degree of arterial enhancement can be achieved by increasing the rate of contrast, independent of the concentration of iodine contrast medium.
Timing Bolus/Bolus Tracking

The timing of contrast bolus administration is critical to obtain optimal opacification of the pulmonary arteries. Incorrect timing is a common cause of suboptimal studies. A fixed scan delay of 20 to 25 seconds was used especially for SDCT and early generation of MDCT scanners, which leads to adequate opacification of the pulmonary arteries in at least 85% of patients with normal cardiac function. However, with the current generation of scanners, a timing bolus or bolus tracking method is more commonly used to optimize opacification of pulmonary arteries.

A timing bolus is usually performed by injecting 15 to 20 mL of intravenous contrast material and placing a region of interest in the pulmonary trunk to obtain a time-density curve from which the scan delay can be calculated. When comparing empirical delay with test bolus, Hartmann and colleagues reported that despite objective improvement in pulmonary artery enhancement, there was no significant difference in image quality.(45)

Additionally, 16% of the studies had to be excluded because of uninterpretable time density curves.

Alternatively, bolus tracking method can be used with a cursor in the main pulmonary artery that triggers scanning at a preset threshold. For the 16-slice scanner, the scan is triggered when a threshold of 120 HU is reached and for the
64- slice scanner, at the first sight of contrast in the pulmonary artery. A timing or bolus tracking method should be used in patients with suspected or known cardiac dysfunction because the optimal scan delay time can be 40 seconds or more.

In larger patients, a larger volume of high- density contrast should be injected at a higher flow rate to improve the signal to noise, a higher kVP should be used, and images should be acquired at thicker collimation of 2.0 to 2.5 mm to decrease quantum mottle.

**ECG Gating**

The benefit of ECG gating in diagnostic PE evaluation is controversial. (46) Only 1% of subsegmental pulmonary arteries are inadequately visualized secondary to cardiac motion artifact using a 4- row scanner at 1-mm collimation. (41) The higher radiation dose secondary to ECG gating is therefore not justified. ECG gating in patients with high or irregular heart rates would lead to considerable artifacts. With MDCT scanners, 16-slice and higher, the addition of ECG gating to the CTPA study can be helpful when there is a need for a double/triple rule-out study to detect or exclude pathology within the pulmonary arteries, aorta, and/or the coronary arteries. Significant stenosis of coronary arteries or nonenhancement of the myocardium in patients with acute myocardial infarction may offer an