

**ASSOCIATION BETWEEN CLINICAL
PARAMETERS AND VENOUS ACCESS WITH THE
IMAGE QUALITY OF COMPUTED
TOMOGRAPHY PULMONARY ANGIOGRAPHY
(CTPA) IN HOSPITAL UNIVERSITI SAINS
MALAYSIA (HOSPITAL USM)**

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LIST OF SYMBOLS, ABBREVIATIONS AND ACRONYMS

ACR	The American College of Radiology
BMI	Body mass index
BP	Blood pressure
CNR	Contrast to noise ratio
CT	Computed tomography
CTPA	Computed tomography pulmonary angiography
HU	Hounsfield unit
ICU	Intensive care unit
IV	Intravenous
Objective PA_{enhan}	Objective pulmonary arterial enhancement
PACS	Picture archiving and communication system
PE	Pulmonary embolism
ROI	Region of interest
SNR	Signal to noise ratio

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ABSTRAK

Objektif:

Kajian ini bertujuan mengenalpasti hubungkait antara parameter klinikal dan akses vena dengan kualiti imej tomografi berkomputer angiografi pulmonari (CTPA) secara objektif dan subjektif.

Bahan dan Kaedah:

Seratus orang pesakit terlibat di dalam kajian ini. Parameter klinikal (jantina, umur, berat badan, tekanan darah, kadar degupan jantung) dikumpul. Saiz dan lokasi akses vena didokumenkan. Penilaian kualiti imej CTPA secara objektif [*pulmonary arterial enhancement* (*Objective PA_{enhan}*), *signal to noise* (SNR), *contrast to noise ratio* (CNR)] diukur. Kualiti imej subjektif dinilai oleh dua orang pakar radiologi secara berasingan.

Keputusan:

Hubungan linear positif dikenalpasti antara umur dan *objective PA_{enhan}* (p-value = 0.007, $\beta = 0.251$), SNR (p-value = 0.007, $\beta = 0.251$), CNR (p-value = 0.001, $\beta = 0.301$), dan kualiti imej subjektif (P-value <0.000, $\beta = 0.450$). Hubungan linear negatif ditunjukkan antara berat badan dan *objective PA_{enhan}* (p-value <0.00, $\beta = -0.473$). SNR (p-value <0.00, $\beta = -0.473$), dan CNR (p-value <0.000, $\beta = -0.462$). Imej kualiti subjektif yang lebih tinggi dilihat di kalangan pesakit lelaki (mean = 3.782) dibandingkan dengan pesakit wanita (mean = 3.156) (p-value = 0.0001). Kualiti imej subjektif yang lebih baik juga dilihat

di kalangan pesakit dengan kanula di bahagian kaki dibandingkan dengan tangan (p-value = 0.02, 95% CI: 0.197, 3.153) atau *antecubital fossa* (p = 0.04, 95% CI: 0.038, 2.839), dan kalangan pesakit dengan kanula di bahagian bawah anggota badan (mean = 4.400) dibandingkan dengan bahagian atas (mean = 3.347) (p-value = 0.014). Tiada hubungkait dikenalpasti antara akses vena dan kualiti imej objektif.

Kesimpulan:

Umur dan berat badan pesakit mempunyai impak yang signifikan ke atas kualiti imej CTPA. Tekanan darah dan kadar degupan jantung tidak mempunyai kesan yang signifikan terhadap kualiti imej. Walaupun pesakit lelaki secara statistiknya didapati menghasilkan kualiti imej subjektif yang lebih baik berbanding wanita, ini berkungkinan tidak signifikan jika dilihat dari sudut klinikal.

Kata kunci:

Computed tomography pulmonary angiography, kualiti imej, parameter klinikal, akses vena, *signal to noise ratio*, *contrast to noise ratio*

ABSTRACT

Objective

This study aims to determine the association between clinical parameters and venous access with the objective and subjective image quality of computed tomography pulmonary angiography (CTPA).

Materials and Methods

One hundred patients were included in our study. Clinical parameters (gender, age, body weight, blood pressure, heart rate) were collected. The size and location of venous access were documented. Objective CTPA image quality assessment [pulmonary arterial enhancement (Objective PA_{enhan}), signal to noise (SNR), contrast to noise ratio (CNR)] were measured. Two radiologists independently assessed subjective image quality.

Results

Positive linear relationship was demonstrated between age and objective PA_{enhan} (p-value = 0.007, β = 0.251), SNR (p-value = 0.007, β = 0.251), CNR (p-value = 0.001, β = 0.301), and subjective image quality (P-value <0.000, β = 0.450). Negative linear relationship was shown between body weight and objective PA_{enhan} (p-value <0.00, β = -0.473), SNR (p-value <0.00, β = -0.473), and CNR (p-value <0.000, β = -0.462). Higher subjective image quality was seen in male (mean = 3.782) compared to female (mean = 3.156) (p-value = 0.001). Better subjective image quality was also seen in patients with IV cannula placed at the foot as opposed to hand (p-value = 0.02, 95% CI: 0.197, 3.153), or antecubital fossa (p = 0.04, 95% CI: 0.038, 2.839), and in patients with IV cannula at

lower limb (mean = 4.400) as opposed to upper limb (mean = 3.347) (p-value = 0.014).

There is no association between venous access and objective image quality.

Conclusion

Patient age and weight showed a significant impact on the image quality of CTPA. Blood pressure and heart rate did not significantly affect the image quality. Even though the males had statistically better subjective image quality than females, this might not be clinically significant due to minimal absolute difference.

Keywords:

Computed tomography pulmonary angiography, image quality, clinical parameters, venous access, signal to noise ratio, contrast to noise ratio

CHAPTER 1: BACKGROUND

1.1 Introduction

Pulmonary embolism (PE) is a common emergency disorder with high morbidity and mortality (Hu *et al.*, 2017). It constitutes 10% of hospital fatalities (Yilmaz *et al.*, 2013) and is the third most common cause of cardiovascular death in the world after coronary artery disease and stroke (Hu *et al.*, 2017).

Computed tomography pulmonary angiography (CTPA) is considered the standard imaging study for diagnosing PE (Marshall *et al.*, 2019; Yuan *et al.*, 2012). In an optimal study, CTPA is very accurate in diagnosing PE, with a sensitivity of 89% and specificity of 95% (Marshall *et al.*, 2019). The visualisation of pulmonary arteries down to the subsegmental level is possible on a good-quality CTPA (Hu *et al.*, 2017). However, a significant proportion of CTPA is indeterminate due to suboptimal quality. Studies have found that 7 - 9% of CTPA is inconclusive. This is worse in the intensive care unit (ICU) patients, whereby the rate of non-diagnostic CTPA is as high as 25% (Roggenland *et al.*, 2008).

In order to achieve a good diagnostic performance of CTPA, optimisation of the image quality is important. The degree of the enhancement of the pulmonary artery is paramount in detecting PE on CTPA. On CTPA, PE appears as a filling defect inside the contrast-filled pulmonary artery. Therefore, a higher degree of arterial enhancement leads to better lesion contrast (Kim *et al.*, 2017). Non-diagnostic image is usually contributed by either suboptimal contrast enhancement or the presence of motion or streak artefact (Hogan *et al.*, 2019; Marshall *et al.*, 2019; Meier *et al.*, 2016). The factors affecting image quality can be divided into technical and patient-related factors. Technical factors include

injection duration, rate and concentration, the use of saline flush and scan timing (Bae and Heiken, 2005; Chaturvedi *et al.*, 2017). Patient-related factors include cardiac output, body weight, venous access, age, gender and height (Bae and Heiken, 2005; Higaki *et al.*, 2018).

1.2 Objective

General:

To determine the association between clinical parameters and venous access with the image quality of CTPA.

Specific:

1. To determine the association between clinical parameters and venous access with the objective image quality of CTPA.
2. To determine the association between clinical parameters and venous access with the subjective image quality of CTPA.

1.3 Hypothesis

1. There is an association between clinical parameters and venous access with the objective image quality of CTPA.
2. There is an association between clinical parameters and venous access with the subjective image quality of CTPA.

1.4 Research Question

1. Is there any association between clinical parameters and venous access with the objective image quality of CTPA?
2. Is there any association between clinical parameters and venous access with the subjective image quality of CTPA?

CHAPTER 2: LITERATURE REVIEW

2.1 Bodyweight

Bodyweight is an important factor for the image quality of CTPA. This is explained by the larger blood volume in a larger patient. The total amount of blood comprises about 8% of the total body weight, and the central blood volume comprises about 1.2% of the total body weight (Saade *et al.*, 2011). The larger blood volume leads to dilution of the contrast medium, leading to a lower vessel enhancement (Bae, 2010). According to Roggenland *et al.* (2008), there is a significant negative correlation between body weight and vessel enhancement, signal to noise ratio (SNR) and contrast to noise ratio (CNR). However, there is no significant correlation between body weight and image noise. Kim *et al.* (2017) compared non-diagnostic to diagnostic CTPA and found a greater body weight in non-diagnostic CTPA. Bae *et al.* (2007) concluded that in order to achieve contrast enhancement of 250 HU, contrast medium volume should be adjusted to the body weight at 1.2 ml/kg.

2.2 Haemodynamic parameters

Hemodynamic parameters comprise of heart rate, blood pressure, stroke volume, total peripheral resistance and cardiac output (Thanachartwet *et al.*, 2016). Some of these parameters are easily measured, such as heart rate and blood pressure. On the other hand, cardiac output measurement is a complex process where invasive or non-invasive techniques can be used. Cardiac output is the product of stroke volume and heart rate and is defined as the volume of blood pumped by the heart per minute (Lavdaniti, 2008).

Cardiac output is considered an important factor in determining vessel enhancement in CT, especially in terms of the timing of the contrast enhancement (Bae and Heiken, 2005). This is based on previous animal study (Bae *et al.*, 1998b), computer simulations (Bae *et al.*, 1998a; Higaki *et al.*, 2018) and flow phantom simulation (Kidoh *et al.*, 2017). In theory, the reduction of cardiac output leads to slowing down the circulation of the contrast medium, leading to delays in contrast bolus arrival and peak arterial enhancement. On the other hand, this also leads to diminished contrast medium dispersion; therefore, leading to increased peak aortic and parenchymal enhancement. Thus, in a patient with a low cardiac output, the peak arterial enhancement is thought to be higher and longer (Bae and Heiken, 2005). Even though this concept is generally accepted, the flow phantom study by Kidoh *et al.* (2017) shows a paradoxical effect of cardiac output on arterial enhancement at a short duration of contrast media injection. On the other hand, Nakaura *et al.* (2011) reported that cardiac output has no effect on the peak aortic enhancement at a short duration contrast agent injection.

In CT coronary angiography, cardiac output has been shown to negatively correlate with arterial enhancement (Flinck *et al.*, 2010; Husmann *et al.*, 2006; Sakai *et al.*, 2010; Tomizawa *et al.*, 2012). However, there is no similar study done on CTPA. A study comparing the image quality of CTPA in pregnant and non-pregnant patients shows a higher rate of non-diagnostic CTPA in pregnant women (Hogan *et al.*, 2019). This is attributed to the physiological haemodynamic changes in pregnancy and is explained by the increase of the cardiac output in pregnancy, initially by the rise in the heart rate, followed by an increase in the stroke volume (Schaefer-Prokop and Prokop, 2008).

Compared to cardiac output, studies on the association between heart rate and vessel enhancement are limited. Husmann *et al.* (2006) investigated this association in CT coronary angiography and reported no correlation between heart rate and arterial

enhancement. On the other hand, Zhu *et al.* (2012) stated a negative correlation between heart rate and arterial enhancement even when the contrast agent is individualised according to gender, weight and body mass index (BMI). There is no study done to look at this association in CTPA.

2.3 Venous access

The American College of Radiology (ACR) recommends using at least a 20-gauge intravenous (IV) cannula in the antecubital fossa or forearm to perform a CT angiography, and many hospitals follow this recommendation. Even though this recommendation intends to improve the image quality of CTPA, it may result in a significant delay in diagnosis in patients with difficult venous access (Marshall *et al.*, 2019). Despite this recommendation, there are scanty studies on venous access's effect on CT image quality, and the findings are inconsistent.

According to Roggenland *et al.* (2008), the use of central venous access, when compared to peripheral venous access, leads to lower quality of the image. This is because of the direct injection of contrast agent into the superior vena cava or right atrium, causing an immediate circulation and early pulmonary washout. However, there is no significant difference when comparing different sites and sizes of peripheral venous cannula (including lower limb). On the contrary, Kim *et al.* (2017) reported that the rate of non-diagnostic studies is higher when a contrast agent is administered via the leg vein compared to the arm vein. Marshall *et al.* (2019) found that the rate of non-diagnostic CTPA is slightly reduced in patients with large IV cannula in antecubital and forearm fossa; however, it is not statistically significant. They suggested that, in emergency cases,

CTPA should be performed even when the venous access site and size do not meet the recommendation by ACR.

2.4 Assessment of image quality

In current literature, there are some variations in terms of the methods used to assess the image quality of CTPA. This can be divided into objective and subjective assessments.

The most commonly used objective image quality assessment parameter is an objective pulmonary arterial enhancement (Objective PA_{enhan}). This is done by measuring CT numbers by placing a region of interest (ROI) in a few locations in pulmonary arteries. In the study done by Szucs-Farkas *et al.* (2014), only the main pulmonary artery was used as the point of measurement. Kim *et al.* (2017) used three measurement points: the pulmonary trunk and right and left main pulmonary arteries. The greatest number of points of measurement used was in studies by Roggenland *et al.* (2008) and Hu *et al.* (2017). They did the CT number measurement in nine points: the main pulmonary artery, right and left pulmonary arteries, both lower lobe arteries, both upper lobe arteries, lingular artery and middle lobe artery. The higher the CT number, the higher the image quality. The mean of the CT numbers is calculated from these measurements. Objective PA_{enhan} of less than 250 HU is considered non-diagnostic. (Kim *et al.*, 2017).

Signal to noise ratio (SNR) and contrast to noise ratio (CNR) can also be measured as part of the objective assessment. In order to calculate the SNR, the background noise is measured by placing the ROI in the surrounding air, and the SNR is calculated by using the equation: $SNR = \text{Objective PA}_{\text{enhan}} / \text{background noise}$ (Hu *et al.*, 2017; Lee *et al.*, 2016; Lu *et al.*, 2014; Roggenland *et al.*, 2008). The background CT number is obtained

by measuring the CT number of either latissimus dorsi muscles (Lee *et al.*, 2016), paraspinal muscles (Lu *et al.*, 2014; Roggenland *et al.*, 2008; Szucs-Farkas *et al.*, 2014) or periscapular muscle (Meier *et al.*, 2016) to calculate the CNR. The CNR can then be calculated by using the equation: $CNR = (Objective\ PA_{\text{enhanced}} - \text{background CT number}) / \text{background noise}$.

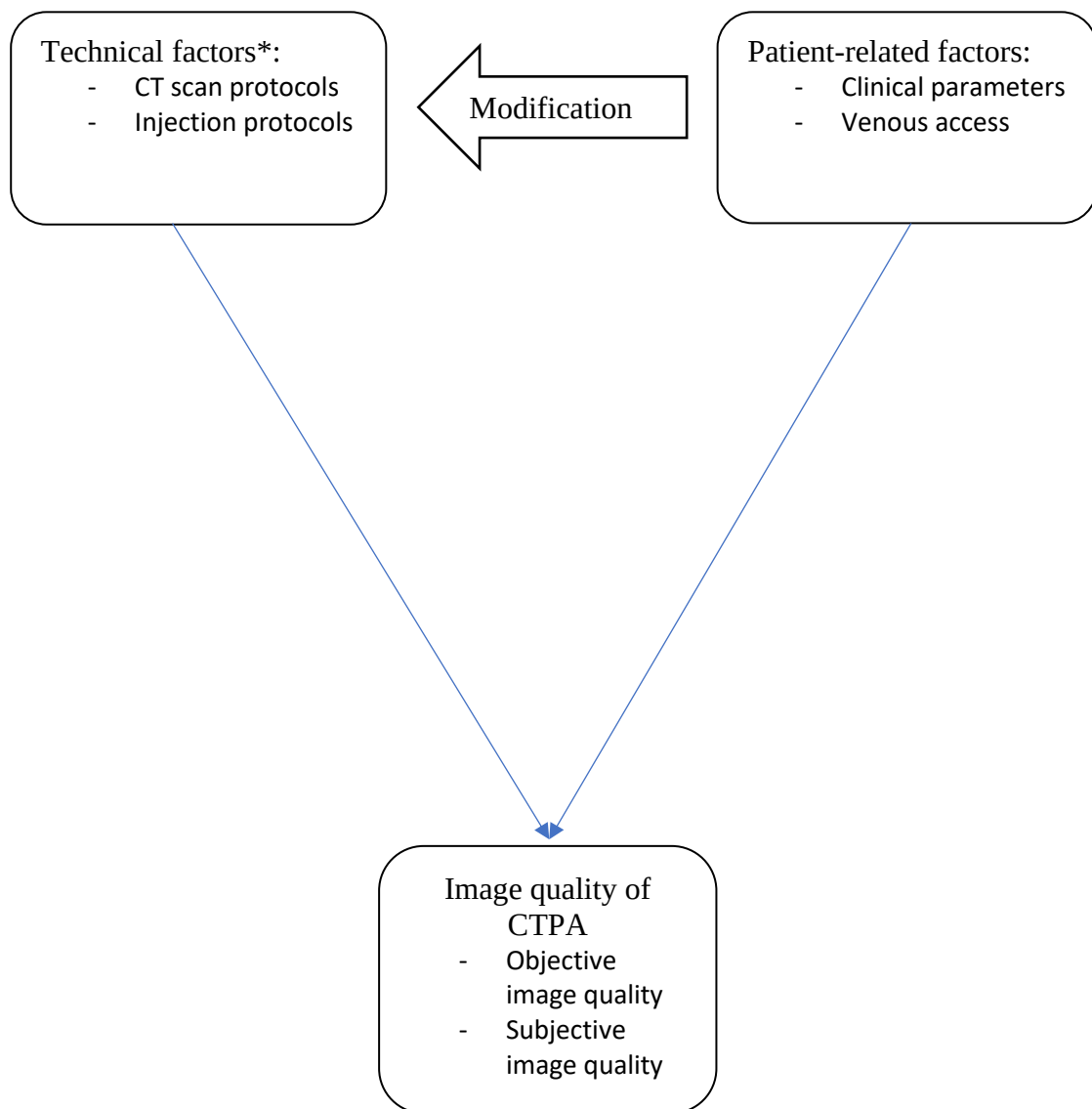
For subjective assessment, the most commonly used method is subjective grading by radiologists by using either a 3-point scale (Lu *et al.*, 2014), a 4-point scale (Meier *et al.*, 2016) or a 5-point scale (Godoy *et al.*, 2011; Lee *et al.*, 2016; Roggenland *et al.*, 2008; Yilmaz *et al.*, 2013; Yuan *et al.*, 2012). Roggenland *et al.* (2008), Godoy *et al.* (2011), and Lu *et al.* (2014) used an entirely subjective scale. On the other hand, Yuan *et al.* (2012) and Lee *et al.* (2016) divided the assessment into two categories: pulmonary arterial enhancement and image noise. Yilmaz *et al.* (2013) did the grading using three categories: image quality, pulmonary arterial enhancement, and motion artefact.

2.5 Rationale of the study

CTPA is an essential imaging modality done to rule out pulmonary embolism. However, its interpretation is affected by the quality of the final images acquired. Several studies have been done previously to look at different factors influencing image quality. This study aims to determine the association between clinical parameters and venous access with the image quality of CTPA. There is only a limited study done to look at the effect of heart rate or blood pressure on the CTPA image quality. There are studies on the association between IV cannula location and size with the image quality of CTPA; however, the results are inconsistent. If any association is found, these parameters could

be used as indicators to appropriately modify the CTPA protocols in selected patients to obtain good-quality images.

2.6 Conceptual framework



*Not being studied

CHAPTER 3: METHODOLOGY

3.1 Study design

Cross-sectional study.

3.2 Study location and duration

The study was conducted in Hospital Universiti Sains Malaysia (Hospital USM) from 1st February 2020 until 30th November 2021.

3.3 Study population and sample

Reference population:

Patients who were suspected of having pulmonary embolism in Hospital USM.

Target population:

Patients who were investigated for pulmonary embolism with CTPA in Hospital USM.

Source population:

Patients who were investigated for pulmonary embolism with CTPA in Hospital USM from 1st February 2019 to 31st January 2020.

Sampling frame:

Patients who were investigated for pulmonary embolism with CTPA in Hospital USM from 1st February 2019 until 31st January 2020 who fulfilled the inclusion and exclusion criteria.

3.4 Sampling technique

Purposive sampling method

3.5 Inclusion criteria

- All patients underwent CTPA with available 'CTPA technique & protocol document' forms.
- CTPA was performed using a Toshiba Aquilion Prime CT scan.

3.6 Exclusion criteria

- CTPA was performed with modified protocols.
- Age less than 18 years old.
- Incomplete images stored in the PACS system

3.7 Sample size calculation

Objective 1

According to Roggenland *et al.* (2008):

- Bodyweight has a negative correlation with the objective PA_{enhan} ($r = -0.473$).
- No significant association between venous access and the objective PA_{enhan} .

There is no data regarding the association between heart rate and blood pressure with the objective PA_{enhan} . In CT coronary angiography, heart rate has a negative correlation to vessel enhancement ($r = -0.404$)(Zhu *et al.*, 2012).

Sample Size Calculator for Correlation Analysis v3.0 developed by Najib (2015) was used.

For bodyweight, the calculated sample size was 37, as shown below:

Sample Size Calculator for Correlation Analysis, (test null hypothesis of $r = 0$)	
Instruction: enter data in green cells read output in gray cells	
Correlation coefficient, $r =$	-0.473
Type I error, $\alpha =$	5%
Type II error, $\beta =$	20%
Calculated sample size, $n =$	33
Anticipated dropout rate =	10%
Corrected sample size, $n_c =$	37

Figure 1: Sample size calculation for correlation between body weight and objective image quality.

For heart rate, the calculated sample size was 52, as shown below:

Sample Size Calculator for Correlation Analysis, (test null hypothesis of $r = 0$)	
Instruction: enter data in green cells read output in gray cells	
Correlation coefficient, $r =$	-0.404
Type I error, $\alpha =$	5%
Type II error, $\beta =$	20%
Calculated sample size, $n =$	46
Anticipated dropout rate =	10%
Corrected sample size, $n_c =$	52

Figure 2: Sample size calculation for correlation between heart rate and objective image quality.

Objective 2

According to Roggenland *et al.* (2008):

- Bodyweight has a negative correlation with subjective pulmonary arterial enhancement ($r = -0.422$).
- No significant association between venous access and subjective pulmonary arterial enhancement.

There is no data regarding heart rate and blood pressure.

Sample Size Calculator for Correlation Analysis v3.0 developed by Najib (2015) was used.

For bodyweight, the calculated sample size was 47, as shown below:

Sample Size Calculator for Correlation Analysis, (test null hypothesis of $r = 0$)	
Instruction: enter data in green cells read output in gray cells	
Correlation coefficient, $r =$	-0.422
Type I error, $\alpha =$	5%
Type II error, $\beta =$	20%
Calculated sample size, $n =$	42
Anticipated dropout rate =	10%
Corrected sample size, $n_c =$	47

Figure 3: Sample size calculation for correlation between body weight and subjective image quality.

For multiple linear regression analysis, sample size calculation was also performed using G*Power software version 3.1.9.4. In view of some of the independent variables have been found to have a fair correlation ($0.25 < r < 0.5$) with the image quality as mentioned above, the effect size was assumed to be medium ($f^2 = 0.15$). Based on this assumption, the calculated sample size was 103, as shown below:

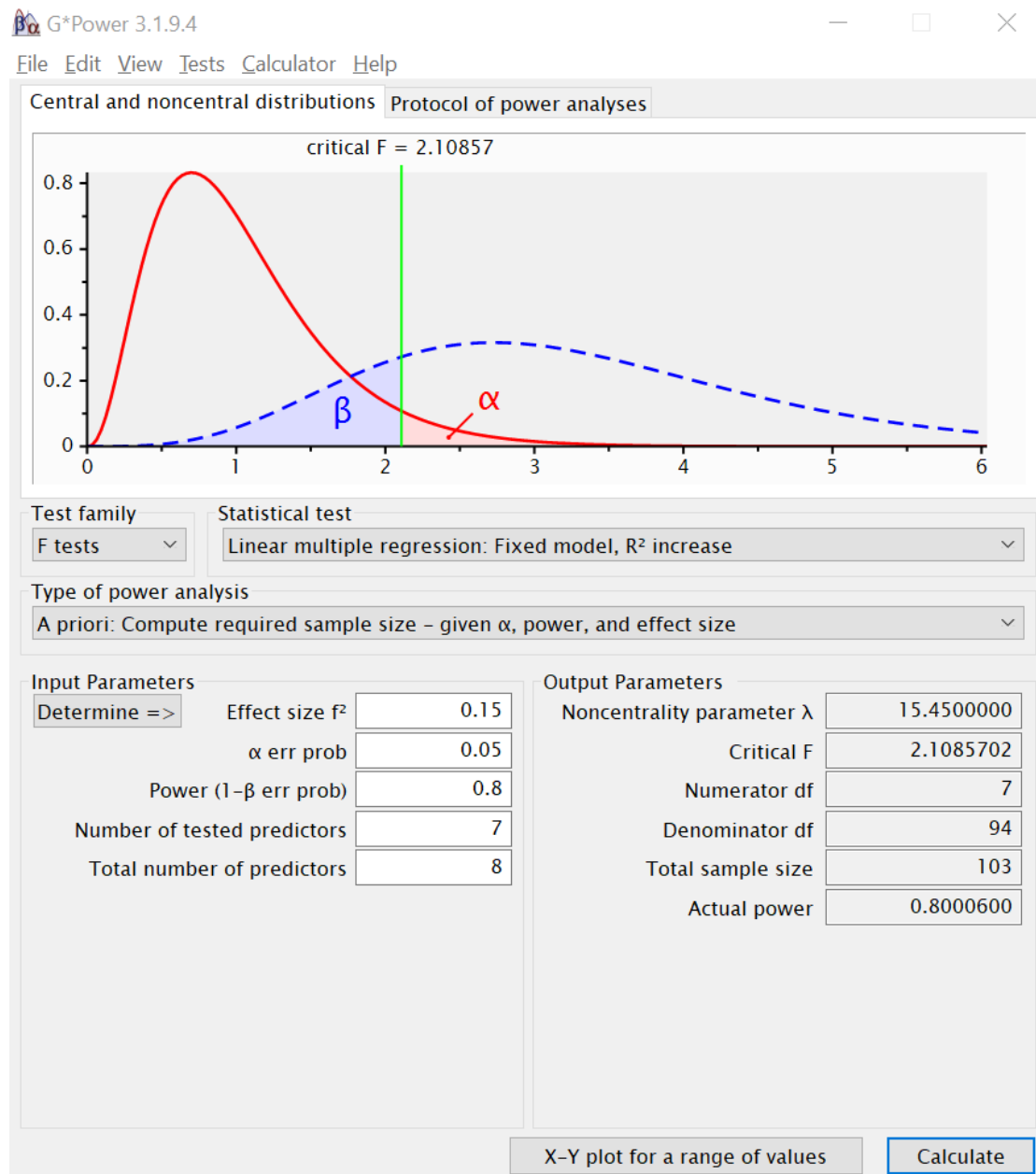


Figure 4: Sample size calculation for multiple linear regression.

Based on these calculations, the largest calculated sample size was 103. Therefore, this was the sample size that was used in our study.

3.8 Research tool

1. 'CTPA technique & protocol document' form (Appendix A)
2. Picture archive and communication system (PACS), Centricity PACS, GE Healthcare, Universal Viewer version 6.0
3. Image quality assessment form (Appendix B)

3.9 Operational definitions

1. Objective pulmonary arterial enhancement (Objective PA_{enhan})
 - The average CT number or enhancement level of the pulmonary arteries is measured using the Pictural Archive and Communication System (PACS).
 - The unit used is the Hounsfield unit (HU).
 - The higher the CT number, the higher the quality of the image.
2. Signal to noise ratio (SNR).
 - Objective PA_{enhan} - background noise
 - Background noise is the CT number of the surrounding air.
3. Contrast to noise ratio (CNR).
 - $(\text{Objective } PA_{\text{enhan}} - \text{background CT number})/\text{background noise}$.
 - Background CT number is the CT number of latissimus dorsi muscle, periscapular or paraspinal muscle.
4. Subjective image quality.
 - Subjective level of the image quality as assessed by the radiologists.
 - The following scale is used.

Scale and Score	Description
1	Non-diagnostic
2	Suboptimal
3	Moderate
4	Good
5	Excellent

Table 1: Subjective image quality assessment.

- A completely subjective assessment as deemed fit by the radiologists.
- The higher the score, the higher the subjective image quality.

3.10 Data collection method

CTPA examinations were performed using an 80-row detector Aquilion Prime CT scan (Toshiba, Japan). The patients were examined in a supine position in a standard protocol with both arms extended above the head. The scan was obtained in the caudocranial direction in a single inspiratory breath-hold method covering the whole lungs from the bases to the apices. A tube voltage of 120 kVp was used, and the tube current (mAs) was automatically set by the machine. Intravenous contrast medium was administered using the injector with a volume of 40 to 50 ml and a rate of 4 to 5 ml/s, followed by a saline chase of 60-80 ml with a rate of 4 to 5 ml/s. The bolus tracking technique was used with the region of interest (ROI) placed at the main pulmonary artery, and the scan was triggered at 120 HU.

In our centre, the 'CTPA technique & protocol document' (Appendix A) is filled up by the radiographer on duty for all the patients undergoing CTPA. Relevant information regarding the clinical parameters and venous access (size and location) was obtained from this form. The collected clinical parameters were age, gender, body weight,

blood pressure, and heart rate. The patients' folders were reviewed for incomplete forms to get the missing information.

Using the Picture Archive and Communication System (PACS), the images of the CTPA were assessed for objective and subjective image quality. For the objective assessment, three parameters were used: objective PA_{enhan} , SNR, and CNR. For objective PA_{enhan} , CT numbers were measured at nine locations in the pulmonary arteries: the main pulmonary arteries, bilateral pulmonary arteries, bilateral lower lobe arteries, bilateral upper lobe arteries, lingular artery, and middle lobe artery. The elliptical area measurement was used, and the largest possible area was covered for each measurement. The mean CT number was calculated from these measurements. In patients with a thrombus in any of the pulmonary arteries, those specific segments were not measured and excluded from the mean calculation (Hu *et al.*, 2017; Roggenland *et al.*, 2008). Figures 5 – 8 show the examples of the measurements.

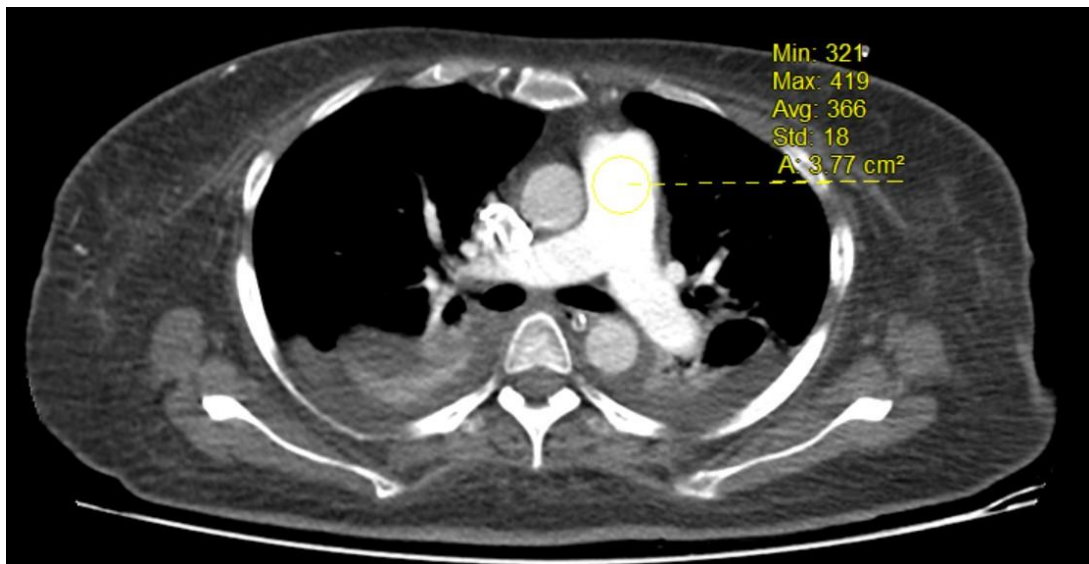


Figure 5: Example of CT number measurement at the main pulmonary artery.

The 'Avg' value was taken as the mean CT number. In this case, it was 366 HU.

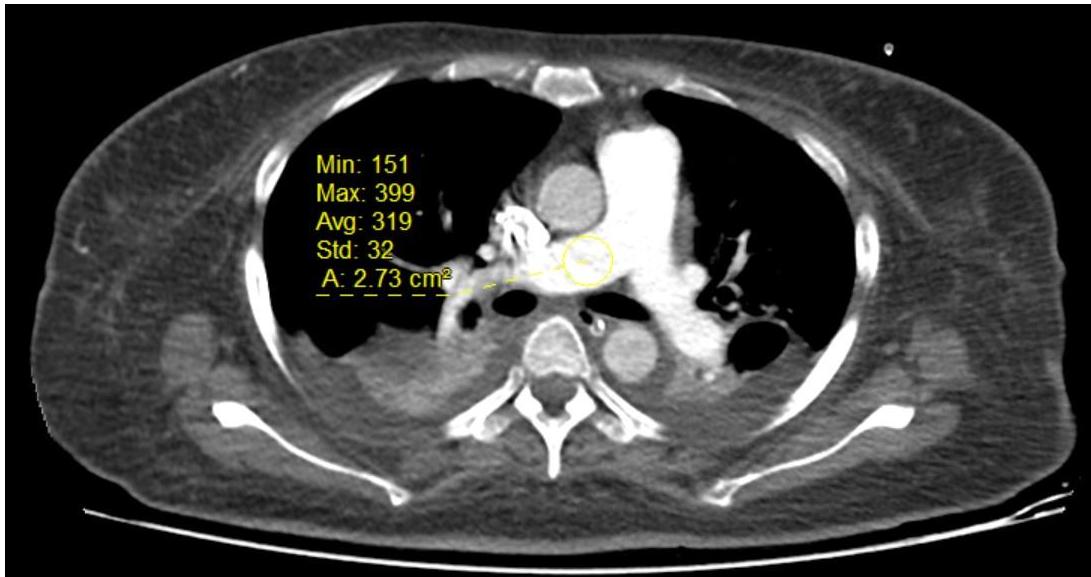


Figure 6: Example of CT number measurement at the right pulmonary artery.

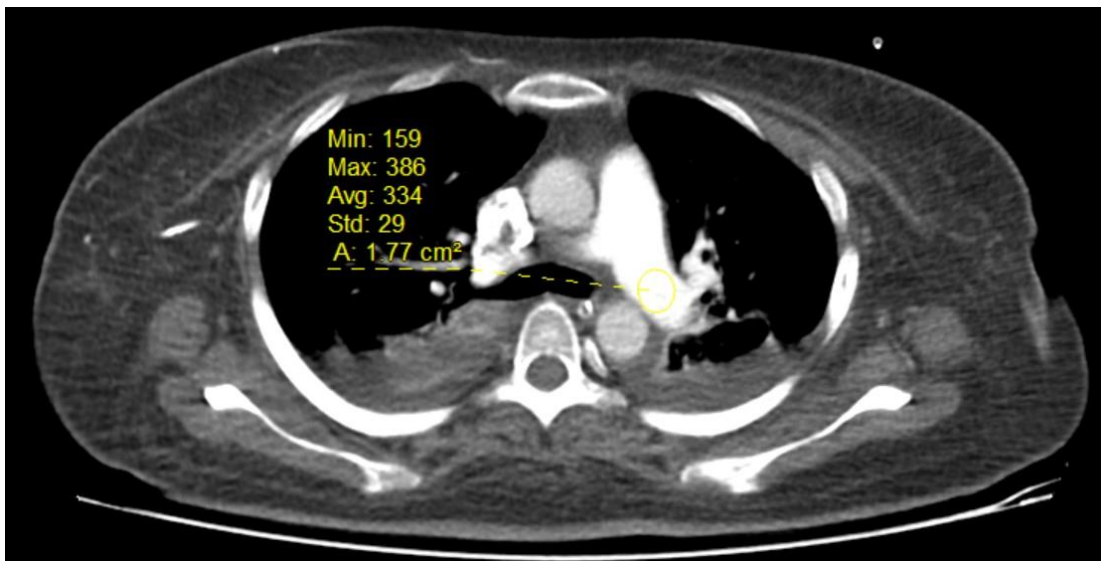


Figure 7: Example of CT number measurement at the left pulmonary artery.

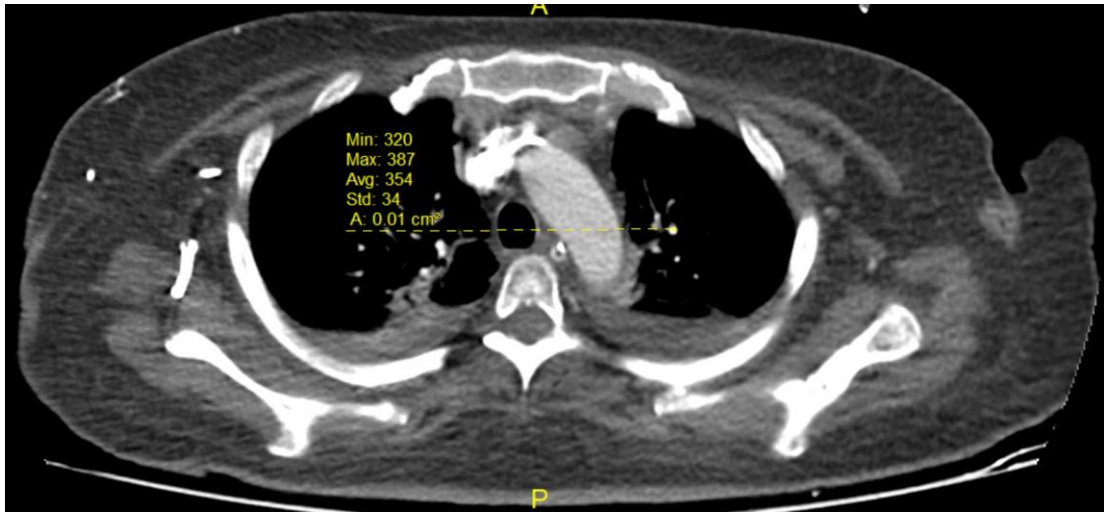


Figure 8: Example of CT number measurement at the left upper lobe pulmonary artery.

For SNR, the background noise was measured by placing the ROI in the surrounding air, and the SNR was calculated using the equation: $SNR = \text{Objective } PA_{\text{enhanced}} / \text{background noise}$. Figure 9 shows an example of the measurement of the background noise. For CNR, the background CT number was obtained by measuring the CT number of paraspinal muscles, and the CNR was then calculated using the equation: $CNR = (\text{Objective } PA_{\text{enhanced}} - \text{background CT number}) / \text{background noise}$. Figure 10 shows an example of the measurement of the background CT number.

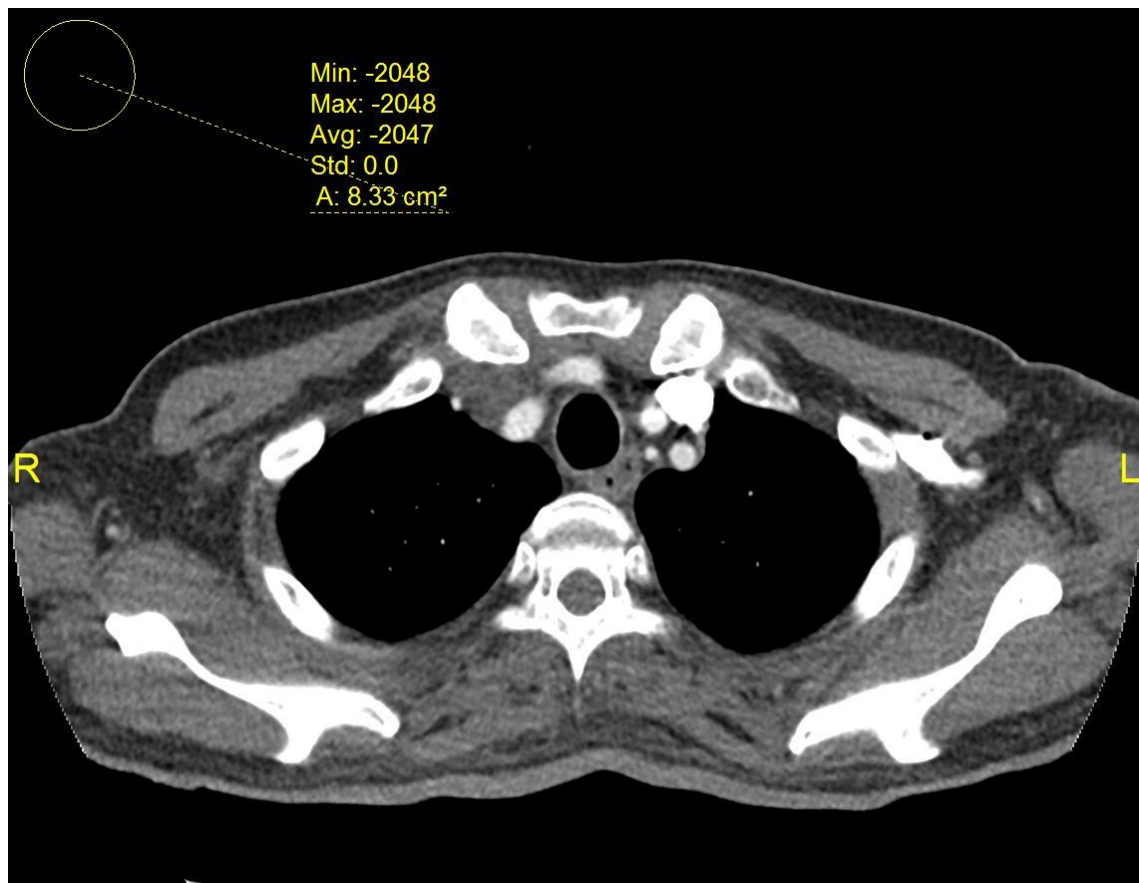


Figure 9: Example of the measurement of the background noise.

$SNR = \text{Objective } PA_{\text{enhan}} / \text{background noise}.$

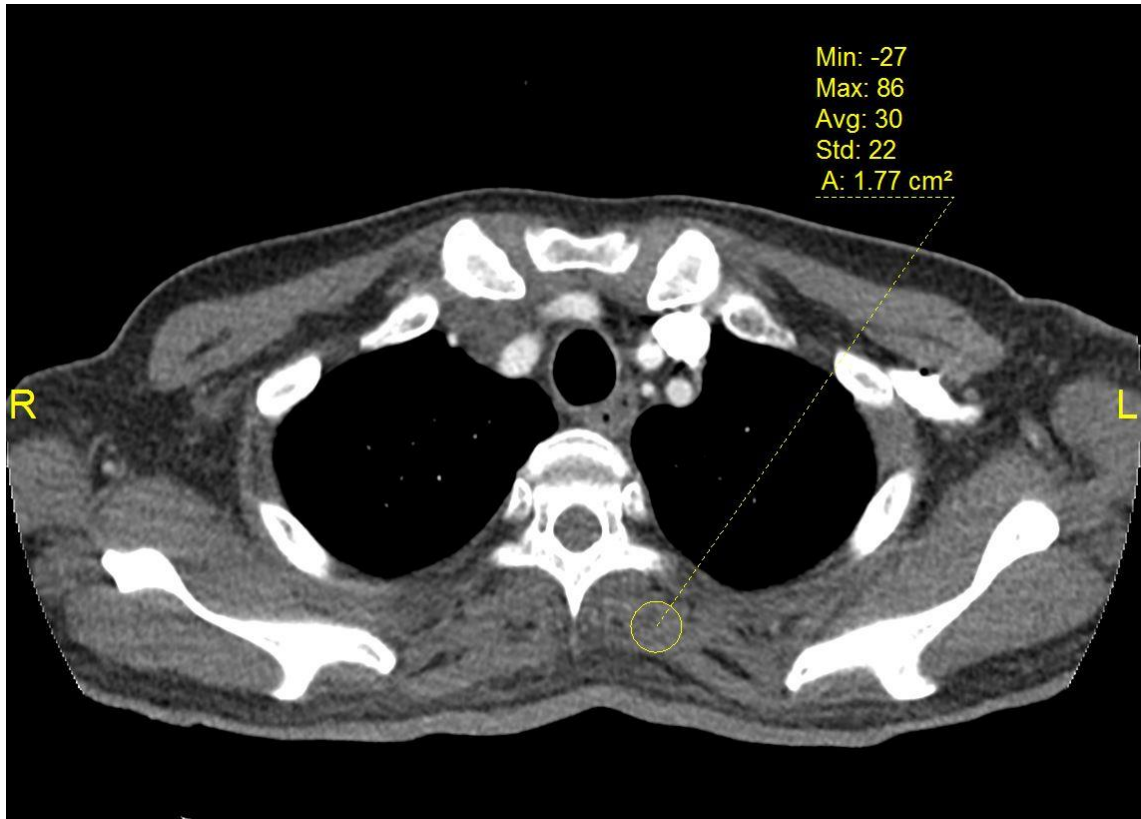


Figure 10: Example of the measurement of the background CT number at left paraspinal muscle.

$$\text{CNR} = (\text{Objective PA}_{\text{enhanced}} - \text{background CT number}) / \text{background noise}.$$

Two radiologists independently assessed the image quality based on a 5-point scale adapted from Roggenland et al. (2008) for subjective image quality assessment. Both radiologists were blinded regarding the patients' clinical parameters and venous access sizes and locations. The mean score was then calculated for each subject. Figures 11 -15 show examples of images with different image quality.



Figure 11: Example of a non-diagnostic study (Scale 1).



Figure 12: Example of a suboptimal study (Scale 2).