ARCHIVES OF HELLENIC MEDICINE: ISSN 11-05-3992

REVIEW
ΑΝΑΣΚΟΠΗΣΗ

ARCHIVES OF HELLENIC MEDICINE 2025, 42(4):457–462
ΑΡΧΕΙΑ ΕΛΛΗΝΙΚΗΣ ΙΑΤΡΙΚΗΣ 2025, 42(4):457–462

A review of computed tomography pulmonary angiogram protocols with low contrast medium volume in delivering diagnostic image quality

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Ανασκόπηση πρωτοκόλλων υπολογιστικής τομογραφίας πνευμονικών αρτηριών με χαμηλό όγκο σκιαγραφικού μέσου για την παροχή διαγνωστικής ποιότητας εικόνας

Περίληψη στο τέλος του άρθρου

Administration of iodinated contrast medium (CM) is essential when performing a computed tomography pulmonary angiogram (CTPA) to visualise the pulmonary arteries and to diagnose or rule out the possibility of a pulmonary embolism. However, potential contrast-induced adverse effects, including nephrotoxicity and allergic reactions, necessitate the reduction of administered CM volume while maintaining image quality in CTPA. This review summarises literature from two electronic databases on the application of reduced CM volume CTPA protocols and the comparison of their image quality with routine CTPA protocols. When medical imaging professionals utilise the capabilities of modern computed tomography scanners, consider patient characteristics to apply patient-specific protocols, and leverage sophisticated image reconstruction techniques, they can reduce the volume of administered CM, while still achieving adequate visualisation of the pulmonary arteries in CTPA. In conclusion, reducing the volume of administered contrast medium in CTPA is feasible, with several techniques and protocols demonstrating efficacy in daily clinical practice.

Key words

Computed tomography pulmonary angiogram
Contrast media
Image quality

Submitted 1.3.2024
Accepted 4.5.2024

1. INTRODUCTION

In the latest years, advances in medical technology have revolutionised the field of medical imaging. Computed tomography pulmonary angiogram (CTPA) is used to identify and evaluate blood emboli in the pulmonary arteries (PA).[1] CTPA has a high sensitivity and specificity in diagnosing or ruling out pulmonary embolism (PE).[2] However, the use of iodinated contrast media (CM) in contrast-enhanced imaging procedures requires caution to ensure patient safety and diagnostic accuracy. Patient safety is a major concern in global healthcare, imposing the need to explore and implement practices that promote safety during diagnostic imaging.[3,4] Radiology departments can substantially reduce the volume of injected CM without negatively affecting the image quality of CTPA exams, by optimising scan parameters, refining imaging techniques, and leveraging modern CT scanner technology. Through these, they can ensure that patients undergo safe and effective imaging procedures.

While CM administration is necessary to obtain contrast-enhanced images of the PA, its use is not without potential risks for the patient. Medication, nutrition and CM allergies, thyroid dysfunction, diabetes, kidney failure and multiple myeloma should be documented and considered before the CM administration, to avoid allergic reactions and contrast-induced adverse effects, potentially fatal for the patient.[5–9] The literature demonstrates an interest in optimising the volume of intravenous CM used in CTPA, aiming to achieve balance between image quality and patient safety.

This review highlights the efficacy of low CM volume CTPA protocols concerning image quality and summarises their outcomes. PubMed and Scopus databases were searched in February 2024 without any time restriction for comparative studies and clinical trials, evaluating image quality of reduced CM volume CTPA protocols. The search term "CTPA" combined with the term "contrast" and either with the term "reduction" or "minimisation" were employed. Full-text articles written in English language were considered for eligibility, if they met the following inclusion criteria: (a) Adult patients with suspected PE undergoing CTPA, (b) studies comparing image quality of a CTPA protocol with reduced CM volume to a standard

CTPA protocol, employing either qualitative or quantitative image evaluation or both, and (c) studies comparing image quality between CTPA protocols with different CM volumes, employing either qualitative or quantitative image evaluation, or both.

2. KEY CONSIDERATIONS IN COMPUTED TOMOGRAPHY PULMONARY ANGIOGRAM

2.1. Choice of contrast medium

The choice of the CM is determined by the imaging protocol and patient characteristics. Higher iodine concentration is preferable for CT angiograms, like CTPA, providing better contrast-to-noise-ratio (CNR) between vessels and surrounding tissues.[10] Nevertheless, lower concentration or volume may be feasible, to minimise the risk of adverse effects, such as extravasation, kidney failure or allergic reactions.[11] The radiology team should be aware of the characteristics of available contrast agents, such as viscosity, osmolality, and iodine concentration, in order to use the contrast agent that best meets the needs of the exam and the patient.[12]

2.2. Ensuring venous sufficiency

As the CTPA relies on the use of CM to visualise the PA, it is crucial for the reduction of the CM volume to minimise the risk of extravasation during injection or suboptimal imaging.[13] A venous catheter suitable for CT angiograms should be used and properly immobilised, to ensure smooth CM injection.[14] The peripheral vein of the right upper limb may be preferred for venous catheterization because of the shorter distance that the CM will have to travel to the cardiac right atrium, compared with the peripheral vein of the left upper limb.[15] In cases of hospitalised or chronically ill patients, where a venous catheter may be placed in lower limbs or a central venous catheter (femoral, jugular or subclavian) is present, the sufficiency of the vein or central line should also be checked, and the examination modified appropriately to achieve optimal PA opacification.[16] A saline flush before and after CM injection can be used, when a dual head power injector is present. The first saline flush can be used, to check the sufficiency of the vein. The second saline flush works as a chaser, flushing the residual CM from the catheter and veins and maintaining CM flow, thus minimising the total volume of CM required for optimal PA imaging.[17]

2.3. Injection technique and scan direction

The position of the peripheral or central venous catheter, as well as the injection technique should be considered when CTPA is performed. If the patient has a peripheral venous catheter to the upper limbs, craniocaudal contrast-enhanced scan can be performed alongside CM bolus-tracking, placing the bolus-tracking locator on the superior vena cava (SVC). In addition, any recorded breath-hold voice command can be deactivated to further reduce scan delay. Similarly, for patients with peripheral venous access to the lower limbs or central femoral venous access, the locator can be placed on the inferior vena cava (IVC) and caudocranial scan direction be applied to minimise scan delay. Placing the bolus-tracking locator near the scan start instead of the pulmonary trunk can reduce table travel delay.[18,19]

A central venous catheter in the jugular or subclavian veins ensures rapid arrival of the CM to the right atrium of the heart. The time from injection start to PA filling with CM is minimised and opacification usually occurs in 7 seconds on average after the injection starts. In this case, the scan can start either manually or the scan delay can be calculated with the test-bolus technique. The scan direction is not a concern, as the central catheter tip extends close to the right atrium, which is in the middle of the chest scan range.[15,20]

Pathological conditions associated with cardiac disease or failure can affect these techniques, leading to suboptimal imaging of the PA. Therefore, the patient's medical history should be considered before CTPA is performed, so that the radiology team can appropriately tailor the examination to achieve optimal PA imaging.[21]

2.4. Contrast injection rate

The injection or flow rate is a key factor in the optimal opacification of the PA. Injection rates of 3–5 mL/sec are usually applied, considering the hemodynamics and venous sufficiency of the patient. Younger patients and pregnant women may require an injection rate close to 5 mL/sec and an increased CM volume, due to the increased cardiac output, to ensure homogeneous opacification of the PA.[22] Instead, an injection rate close to 3 mL/sec may be sufficient for homogeneous opacification of the PA in older patients, if no cardiac dysfunction is present, which could affect cardiac output.[17,23]

2.5. Body mass index

Body mass index (BMI) can affect image quality in CTPA. In patients with higher BMI, achieving optimal image quality may be challenging due to increased body mass. A higher iodine concentration of CM may be required in patients with higher BMI to mitigate a decrease in CNR and

achieve adequate visualisation of the PA. In addition, scan parameters (tube current and voltage) may be adjusted, to optimise image quality in those patients. These adjustments can help to mitigate the effects of increased body mass attenuation, like increased image noise, and improve the visualisation of the PA.[24,25]

3. COMPUTED TOMOGRAPHY PULMONARY ANGIOGRAM WITH REDUCED CONTRAST MEDIUM VOLUME AND IMAGE QUALITY

Several studies have been conducted, investigating the efficacy of reduced CM volume CTPA protocols compared to standard CM volume CTPA protocols. Researchers have concluded that a CTPA protocol employing reduced CM volume compared with routine practice protocol is feasible on a 16-row multi-detector CT scanner (MDCT) with 80 kVp tube voltage, acquiring images with satisfactory diagnostic quality of PA and benefiting patients at risk of Contrast Induced Nephrology (CIN).[26,27] The findings of a comparative study for three bolus-tracking CTPA protocols with different CM volumes have indicated that the two CTPA protocols with decreased CM volumes are feasible and enable adequate PA contrast enhancement, when using a low threshold level to trigger the contrast-enhanced scan and a high injection rate with saline chaser.[17] A comparative study between routine CTPA studies, routine thoracic CT studies and low CM volume CTPA studies performed on a dual-energy MDCT, has revealed that the low CM volume CTPA protocol is feasible when performed with low tube-voltage (kVp), allowing adequate PA contrast enhancement and maintaining comparable image quality to standard contrast-enhanced protocols.[28] Researchers have successfully reduced the iodine load by 25% without affecting the PA enhancement in CTPA, by using a multiphasic injection technique with a reduced volume of high-concentration CM instead of the standard CTPA protocol with the standard volume of low-concentration CM.[29] Another comparative study between two CTPA protocols with different CM volumes has shown that a reduced CM volume by 20% can be used, to provide diagnostic image quality for CTPA examinations.[30] Furthermore, a CTPA protocol with 80 kVp tube voltage and 75 mL CM volume is considered similar to that of 100 kVp CTPA with 100 mL CM volume for patients with weight less than 100 kg. The low-dose and low CM volume CTPA protocol has provided 30% reduced radiation dose and 25% less iodine load, while achieving good image quality for those patients.[31,32] Two additional studies have conducted a comparative analysis of image quality for CTPA protocols that involve simultaneous reduction of CM volume and radiation dose, as compared to standard protocols. Both studies have concluded that patients may safely undergo CTPA by employing a protocol that utilizes low kV and reduced volume of CM.[33,34]

Dual-energy computed tomography (DECT) offers several advantages in the context of image reconstruction, particularly in examinations such as CTPA, where improved CNR is substantial. Researchers have compared the image quality between a standard CTPA protocol with a fixed CM volume and a reduced iodine load CTPA protocol, employing a mixture of CM and saline at the same volume, on a dual-energy CT scanner. The use of the diluted volume along with dual-energy image reconstruction at a low monochromatic level not only allowed a substantial reduction of iodine load and comparable radiation dose to the standard CTPA protocol for the patient, but also improved intravascular signal intensity and maintained CNR.[35,36] As evidenced by another study, dual-energy CTPA protocol may deliver the same image quality with a routine CTPA protocol employing a reduced volume of CM, providing lung perfusion images, and contributing to the diagnosis of PE.[37]

Several researchers have also investigated high-pitch CTPA protocols for their efficacy to deliver sufficient image quality with low CM volume, compared to standard CTPA protocols. A high-pitch CTPA protocol has shown to be feasible at 80 kVp using only 20 mL of CM for normal-weighted patients.[38] Another group of researchers have reached the same conclusion, comparing a high-pitch CTPA protocol at 70 kVp with 40 mL CM to the standard CTPA protocol at 100 kVp with 60 mL CM.[39] In addition, a low kVp high-pitch CTPA protocol with 17 mL of CM has been shown to provide diagnostic image quality in non-obese patients.[40] The potential to reduce the volume of CM for CTPA with a novel photon-counting detector CT using a high-pitch technique has also been investigated. The researchers in those studies have concluded that a significant CM volume reduction is possible without compromising image quality, when using low volume of CM and a high-pitch technique.[41,42] Finally, a high-pitch CTPA protocol with ultra-low CM volume and reduced radiation dose has yielded comparable subjective image quality to standard CTPA protocol in most patients. Although the high-pitch CTPA protocol yielded reduced objective image quality compared to standard CTPA protocol, the diagnostic thresholds for PA opacification and CNR were acceptable for that study.[18]

Other comparative studies have considered several factors and parameters of CTPA protocols affecting the reduction of CM volume. A variation of the test-bolus technique was compared to a bolus-tracking technique during CTPA, to assess whether the first option can lead to CM volume reduction. This comparative study has evidenced that us-

ing the test-bolus technique may reduce the volume of the CM needed, while providing better opacification of the PA and subsegmental branches.[43] Similar outcomes were obtained when applying a CTPA protocol with the test-bolus technique and 10 mL of CM volume at 80 kVp.[44] A study comparing a 70 kVp low-pitch CTPA protocol using 40 mL of CM with a high-pitch and 70 mL of CM has found that the first protocol was just as effective in producing high-quality images. Additionally, the first protocol resulted in a significant reduction in CM and radiation dose compared to the second protocol.[45] Researchers have used a dedicated contrast injection software to deliver body-weighted CM volume and compared image quality between two patient groups. In the first group, patients received an individualised body-weighted CM volume. In the second group, patients received a fixed CM volume to undergo CTPA. The researchers have concluded that individually tailored CM protocols can provide diagnostic image quality in CTPA, facilitating the reduction of CM volume for lower-weight patients.[46] In addition, another study has shown that optimising scan parameters and CM volume based on patient characteristics may provide diagnostic image quality, while facilitating CM and radiation dose reduction.[47] Finally, the impact of patient size on image quality, when applying a low-kVp and reduced CM volume CTPA protocol has been investigated. In that study, a CTPA protocol which combines low tube-voltage and reduced CM volume has provided diagnostic image quality for patients with a maximum weight of 175 lb or 80 kg.[48]

4. CONCLUSIONS

This review aimed to summarise CTPA protocols employing a reduced CM volume, which maintain the clinical efficacy of CTPA in terms of image quality. Original research studies have shown that diagnostic image quality comparable to standard CTPA protocols is achievable by optimising scanning and injection techniques and leveraging advanced CT technologies such as dual-energy and photon-counting CT when utilising lower CM volumes. A limitation of this review was the search of relevant literature in only two electronic databases. Another limitation was the inclusion of comparative studies only, but there were also non-comparative studies investigating the clinical efficacy of low CM volume CTPA protocols. In conclusion, as CTPA is considered a golden standard in diagnosing PE, medical imaging professionals must keep pace with the most recent evidence-based practices, leverage available medical technology and consider the clinical condition and characteristics of each patient, to promote patient safety and deliver accurate image quality and diagnosis.

ΠΕΡΙΛΗΨΗ

Ανασκόπηση πρωτοκόλλων υπολογιστικής τομογραφίας πνευμονικών αρτηριών με χαμηλό όγκο σκιαγραφικού μέσου για την παροχή διαγνωστικής ποιότητας εικόνας

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Η χορήγηση ιωδιούχου σκιαγραφικού μέσου (ΣΜ) είναι απαραίτητη κατά την εκτέλεση της υπολογιστικής τομογραφίας πνευμονικών αρτηριών (CTPA), για την απεικόνιση των πνευμονικών αρτηριών και για τη διάγνωση ή τον αποκλεισμό της πιθανότητας πνευμονικής εμβολής. Ωστόσο, οι πιθανές ανεπιθύμητες ενέργειες που προκαλούνται από το σκιαγραφικό μέσο, συμπεριλαμβανομένης της νεφροτοξικότητας και των αλλεργικών αντιδράσεων, απαιτούν τη μείωση του χορηγούμενου όγκου ΣΜ, διατηρώντας παράλληλα την ποιότητα εικόνας στη CTPA. Η παρούσα ανασκόπηση συνοψίζει τη βιβλιογραφία από δύο ηλεκτρονικές βάσεις δεδομένων σχετικά με την εφαρμογή πρωτοκόλλων CTPA μειωμένου όγκου ΣΜ και τη σύγκριση της ποιότητας εικόνας τους με πρωτόκολλα ρουτίνας CTPA. Όταν οι επαγγελματίες της ιατρικής απεικόνισης χρησιμοποιούν τις δυνατότητες των σύγχρονων αξονικών τομογράφων, λαμβάνουν υπ' όψιν τα χαρακτηριστικά του ασθενούς για την εφαρμογή εξατομικευμένων πρωτοκόλλων εξέτασης και αξιοποίησης των εξελιγμένων τεχνικών ανακατασκευής εικόνας, μπορούν να μειώσουν τον όγκο του χορηγούμενου ΣΜ, ενώ παράλληλα επιτυγχάνουν αποδεκτή απεικόνιση των πνευμονικών αρτηριών στη CTPA. Συμπερασματικά, η μείωση του όγκου του χορηγούμενου ΣΜ στη CTPA είναι εφικτή, με αρκετές τεχνικές και πρωτόκολλα να αναδεικνύουν αποτελεσματικότητα στην καθημερινή κλινική πράξη.

Λέξεις ευρετηρίου: Ποιότητα εικόνας, Σκιαγραφικά μέσα, Υπολογιστική αγγειογραφία πνευμονικών αρτηριών

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