Effect of different contrast administration protocols on contrast enhancement and image quality in CT scan

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Research note

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Abstract

Objective The aim of this study is to compare the effect of different contrast administration protocols practiced in Advanced Medical and Dental Institute, Universiti Sains Malaysia (Group A) and Hospital Pulau Pinang, Malaysia (Group B), on contrast enhancement and image quality in computed tomography scan. The two protocols were fixed time delay (FTD) with fixed volume (FV), and automatic bolus tracking (ABT) with weight based volume (WBV) contrast administration. Quantification of contrast enhancement's magnitude in four different anatomical structures was measured in Hounsfield Unit (HU) and based on 5-point scale (1=poor, 5=excellent), the images were rated qualitatively.

Results Mean enhancement values of all structures in Group B was higher compared to Group A (p = < 0.001). Mean of quality rating between the two groups was statistically not significant (p = 0.185). There was a weak correlation between HU values and administered contrast volume (r = 0.152). It can be concluded that FTD with FV protocol is non inferior to ABT with WBV protocol as it yielded higher degree of contrast enhancement. There was no significant difference between the two protocols in term of qualitative assessment although ABT with WBV protocol had higher mean grading in image quality.

Introduction

Computed tomography (CT) is vital in identification and treatment of clinical conditions as the use of intravenous (IV) contrast in CT protocols helps in distinguishing vascular structures, and the need for enhancement depends on case-by-case basis. As the CT evolves throughout the years in term of scanning speed, it is more or less has frustrates users whom use the old contrast media (CM) and scanning protocols. For optimisation of contrast enhancement for each target organ, this has then led the users to adjust their current practice and acquisition protocols accordingly [1–4].

The most common protocols for contrast administration are test bolus (TB), automatic bolus tracking (ABT) and fixed time delay (FTD) which help to provide information on CT scan timing. With fast scanners, TB method is the common technique being used, which based on injection of small test bolus of CM, followed by series of low radiation dose, and changes in enhancement were then plotted in time-enhancement curve. This technique can be effective in determining the scan delay for a single patient, but requires additional volume of CM and time consuming [5, 6]. ABT technique became the popular choice for fast CT scanner as its capability to detect the vascular phase. A series of low radiation scans were taken after a full bolus of CM injection. After a predetermined enhancement threshold (50–150 HU) in selected ROI has been reached, regular scanning were triggered. For patients with single injection of CM, this technique helps to determine the scan delay appropriately [3, 5, 6]. By tradition, FTD has been used to determine the delay time from the start of CM injection and the start of CT acquisition. The delay time is decided based on previous data and operator's understanding and experience, regardless of patients’ individual variations that may affect differences in arrival times of CM in individual. Nonetheless, for patients with no underlying cardiovascular disorder, this technique was capable of producing a good quality image and contrast enhancement [7–9].
In CT imaging, contrast enhancement is affected by various interacting factors and it can further divided into patient-, CM- and CT scanning-related factors. There are factors which are beyond operator’s control, such as inter-patients variations, body weight and height, cardiac output and circulation time. However, some key parameters in determining CT image quality are controllable by operator, such as tube potential and current, CM volume and injection rate, and saline flush [3].

**Methods**

Data of 140 patients, whom underwent contrast-enhanced CT thorax examination at two centres i.e. Advanced Medical and Dental Institute (IPPT), Universiti Sains Malaysia, and Hospital Pulau Pinang (HPP), Malaysia within the period of July 2014 to December 2015 were retrospectively collected. Patients aged 18 years old and above whom underwent CT examination using 16-slice scanner at each centre were included, and patients with underlying shock, renal impairment and heart disease were excluded. Specific exclusion criteria for IPPT include patients whom were administered with non-weight based volume (WBV) CM and scanned with non-ABT technique. As for HPP, patients that were administered with non-fixed volume (FV) CM and scanned with non-FTD technique were excluded. 70 patients’ data from IPPT was classified as Group A: 19 males and 51 females, with mean age ± SD of 53.6 ± 11.2 years (age range 29 to 77 years), and mean weight ± SD of 54.04 ± 13.77 kg (weight range 32 to 100 kg). As for patients’ data from HPP, which was identified as Group B: 24 males and 46 females, with mean age ± SD of 54.5 ± 13.2 years, and age ranged between 20 to 80 years. In HPP, patient’s weight was not recorded.

Group A patients underwent CT thorax examination using ABT technique and the total volume of CM administered was given according to the patient’s body weight. CM was injected using dual injector at a rate of approximately 4.0 ml/s followed by saline flush at similar rate. The concentration of CM used was of 350 mgI/ml and total iodine injected was kept constant at 400 ml/kg. For Group B, the patients underwent the same procedure of CT thorax examination, scanned using FTD technique, administered with CM of 300 mgI/ml. A FV CM of 80 ml were injected using a dual injector at a rate approximately 1.5 to 2.0 ml/s followed by saline flush at similar rate (Table 1).

All CT images from both centres were then assessed in terms of quantitative and qualitative by two experienced radiologists (of more than three years experiences) from both centres. During assessment session, the assessors were blinded to the scanning techniques and contrast administration protocol. Osirix DICOM (Bernex, Switzerland) was used in quantitative analysis session. This analysis was performed by placing the region of interest (ROI) manually in selected anatomical structures, at the ascending aorta (AA), main pulmonary trunk (PT) (before its bifurcation into the right and left artery), superior vena cava (SVC) and pulmonary vein (PV). The attenuation readings of each structure were recorded in Hounsfield Unit (HU) (Figure 1). During the ROI placement, vascular calcification was excluded. In independent and separate session, the same CT images that were analysed in the first session, were also being assessed qualitatively. CT images were graded based on five predetermined characteristics: 1 = very poor, 2 = poor, 3 = fair, 4 = good, 5 = excellent, to express its overall image quality. It will be graded 1 if the vessel was indistinguishable from surrounding and there was absence or
minimum vascular enhancement. Grade 2 was given to images that show slight vascular enhancement and some contrast between vessels and surrounding structures; grade 3 if vascular enhancement and contrast between lesions and surrounding structures were present but some images were inadequate for evaluation. If the vascular enhancement and contrast between vessels and surrounding structures were present in all the images in a level that allows proper but not easy evaluation of images, a grade 4 was given; grade 5 was given for images with marked vascular enhancement and strong contrast between vessels and surrounding structures. The mean of attenuation values were assessed for both group and compared to each other. In order to find the relationship between HU and administered contrast volume, Pearson's correlation coefficient \( r \) was performed. Mean of qualitative scores for both groups were assessed and compared, and p value less than 0.05 was considered statistically significant. Statistical analysis was performed using commercially available software, IBM SPSS Statistics 24.

**Results**

Comparing Group A and Group B, the mean contrast enhancement in Group B was greater \( (p < 0.001) \). The mean attenuation (represented as HU ± SD) for each anatomical structure for Group A and B were as follows; AA were 174.8 ± 33.0, 229.2 ± 54.1, SVC were 161.9 ± 47.3, 327.9 ± 123.4; PT were 170.3 ± 37.8, 227.1 ± 58.5, and PV were 165.1 ± 35.5, 222.3 ± 53.6, respectively (Table 2). Mean of qualitative scores based on 5-point scale showed no significant difference \( (p = 0.185) \) between Group A \( (4.4 ± 0.6) \) and Group B \( (4.3 ± 0.7) \). A positive but weak correlation was seen between HU values with administered contrast volume, \( r = 0.1152 \).

**Discussion**

Tube voltage (kV) and tube current (mA) are the two main factors that influence the degree of contrast enhancement and image quality. Tang et al. in his study found that noise values at 80 kV, 150–650 mAs were significantly higher when compared to 120 kV, 300 mAs. This effect was supported by previous study, which proved that image noise was inversely correlated with tube current \([10]\). Alsleem and Davidson stated that decrease in mA value will increase the image noise and lower kV, as a result of reduced total energy flux that will decrease image noise, leading to better image contrast enhancement \([11]\). Study by Raman et al. stated that improvement of image quality with low image noise was due to the use of high tube current \([12]\). In this study, a higher degree of contrast enhancement for Group B may be contributed by the utilisation of high tube current with value of 300 mAs and standard tube voltage of 120 kVp, as compared to acquisition protocol for Group A that utilised the tube current ranged between 98 to 395 mAs (average, 98 mAs).

In previous study, quantitative analysis of the liver venous phase and delayed phase showed no significant difference between ABT and FTD technique \([13]\). The preference of FTD protocol was because it simplified the workflow even though the two techniques were actually comparable. It is found that there was no significant difference in parenchymal enhancement between ABT and FTD technique in Mehnert’s study \([13]\). Adibi et al. compared liver enhancement between ABT and FTD technique and found that there
was no significant difference in contrast enhancement of the aorta and spleen at arterial phase, but has no effect on liver enhancement [14]. As for CT scanning in children, White reported that better results was yielded by FTD trials and recommended that after CM administered, the scan to start initiate after a delay of 10–20 second. [15]. After a qualitative assessment for contrast enhancement in the inferior vena cava, Ruess et al. concluded that ABT method was inferior than FTD technique as the enhancement was reduced significantly [16]. In patients with normal cardiac function, tailoring the scan delay to each patient does not improve the uniformity of aortic enhancement of when compared to FTD technique. Rubin et al. in his study chose the FTD with 20 seconds delay for 13 out of 15 subjects in order to achieve complete abdominal aortic opacication on their CT angiogram, and 11 of them achieved the objective [17]. 67% of the study subjects by Bonaldi et al. scored 2.5 points out of 3 for qualitative assessment when FTD with 15 second delay was used during scanning [18].

SD value for all structures in Group B patients were higher when compared to SD value of all structures in Group A. A larger SD shows that there were high variation in the data sets. When a FV of CM was used in his study, Benbow et al. reported that, the SD of portal liver enhancement was 110 ± 25.1 HU, which was higher than the SD of the same structure when a WBV was used, 108 ± 11.9 HU [19]. This study concluded that there was 37% increment for ideal enhancement (100–125 HU) if CM volume were tailored to patient weight. Choi et al. also reported that if a short injection duration with a FV of CM was used, the contrast enhancement will be increased [20].

In this study, it is found that there was positive but weak correlation between HU values and administration volume of CM. Frush et al. demonstrated that FV CM protocol yielded better contrast enhancement even though this method scored lower grade in qualitative assessment [21]. Regardless of the technique used, in achieving comparable vascular enhancement and satisfactory image quality, Laurent et al. suggested that CM administration protocol should be individualised according to patient habitus [22].

As a conclusion, FTD technique with FV CM protocol yielded a higher degree of contrast enhancement for routine CT thorax examination compared to ABT protocol in this study. However, in terms of image quality, ABT with WBV protocol scored higher grades although not statistically significant. For future work, in order to achieve and reap the full benefits of fast scanning multi-detector CT scanner, we must consider the effect of individual habitus on image quality and the CM administration protocol should be individualised and optimised by considering all the factors affecting degree of contrast enhancement and image quality. Validity of each technique in clinical practice should be investigated for future study.

**Limitations**

One of the main limitations of the study was the difference in exposure setting (tube current, mAs), CM volume and concentration used in both centres. Patient-related factors such as body size and cardiac output may have also affected the contrast enhancement. However, we have reduced other limitations by strictly using predefined inclusion criteria for this study.
List Of Abbreviations

ABT: Automatic bolus tracking
AA: Ascending aorta
CM: Contrast media
CT: Computed tomography
FTD: Fixed time delay
FV: Fixed volume
HPP: Hospital Pulau Pinang
HU: Hounsfield unit
IPPT: Advanced Medical and Dental Institute
IV: Intravenous
JEPeM-USM: Jawatankuasa Etika Penyelidikan Manusia, Universiti Sains Malaysia
kV: kilovoltage
mAs: miliampere second
MREC: Ministry of Health Medical Research Ethics Committee
PT: Pulmonary trunk
PV: Pulmonary vein
ROI: Region of interest
SD: Standard deviation
SNR: Signal to noise ratio
SVC: Superior vena cava
TB: Test bolus
USM: Universiti Sains Malaysia
WBV: Weight-based volume
Declarations

Ethics approval and consent to participate

This non-interventional study has been approved by Jawatankuasa Etika Penyelidikan Manusia, Universiti Sains Malaysia (JEPeM-USM); USM/JEPeM/15090297, and The Ministry of Health Medical Research Ethics Committee (MREC); NMRR-15-2271-24987. The ethical committee deemed that patient written informed consent was not required due to the retrospective nature of the study. Official letters were obtained from IPPT, USM and HPP authorities before reviewing the data. The confidentiality and privacy of patients’ data were actively protected. All data were assigned a unique identification number.

Consent for publications

Not applicable.

Availability of data and material

The data used to support the findings of this study are available from the corresponding author upon request.

Competing interests

The authors declare that they have no competing interests.

Author’s contributions

NKAK, ILS, and SH conceived and designed the study. NKAK, ILS, PHF, and SH coordinated the running of the study. NKAK, ILS, and PHF conducted data collection. NKAK, ILS, PHF and NDO have participated in data analysis. NKAK, NRI, and NDO drafted the manuscript. NKAK, NRI, ILS, NDO, PHF, and SH contributed to the interpretation of the analysis and critically revised the manuscript. All authors read and approved the final manuscript.

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**Tables**

Table 1 Scanning protocols for Group A and Group B.
| Scanning parameters                                      | Group A                                      | Group B                                       |
|----------------------------------------------------------|----------------------------------------------|-----------------------------------------------|
| Contrast scanning protocols                              | Automatic bolus tracking (ABT)               | Fixed-time delay (FTD)                        |
| Contrast medium administration                           | Weight-based volume (WBV)                   | Fixed volume (FV)                            |
| Contrast medium volume (ml)                              | 48 - 149                                    | 80                                           |
| Tube voltage (kVp)                                       | 120                                          | 120                                          |
| Tube current (mAs)                                       | 98 - 395                                    | 300                                          |
| Contrast medium concentration (mgI/ml)                   | 350                                          | 300                                          |
| Dual injector rate                                       | 4.0 ml/s                                    | 1.5-2.0 ml/s                                 |

Table 2 Mean of HU values of ascending aorta, superior vena cava, pulmonary trunk and pulmonary vein.

| Region of Interest | Group A | Group B | p value |
|--------------------|---------|---------|---------|
|                    | Mean (HU) | SD | Mean (HU) | SD |
| AA                 | 174.8    | 33.9 | 229.2 | 54.1<0.001 |
| SVC                | 161.9    | 47.3 | 327.9 | 123.4<0.001 |
| PT                 | 170.3    | 37.8 | 227.1 | 58.5<0.001 |
| PV                 | 165.1    | 35.5 | 222.3 | 53.6<0.001 |

Figures
Figure 1

Axial contrast-enhanced CT of thorax showing the mean HU values in ascending aorta (1), superior vena cava (2), pulmonary trunk (3) and pulmonary vein (4) that were measured.