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Radiation Physics REVIEW

Double-Low technique: The optimal protocol for Chest CT, Abdomen CT, CT Coronary Angiography and CT Pulmonary Angiography

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ABSTRACT

The main goal in radiology is to obtain high quality images with the least radiation dose to the patient. In order to be achieved diagnostically acceptable Computed Tomography (CT) images with a minimum dose of radiation and contrast media (CM) many approaches have been developed. "Double-Low" technique is an encouraging approach which refers to the combination of low tube voltage and low CM load using an iterative reconstruction algorithm (IR). The purpose of this study is to compare the most recently proposed approaches on "double-low" technique to the standard protocols and determine the optimum protocol for each anatomical region. Regarding the abdominal CT a reduction in the $CTDI_{vol}$ and CM load of up to 20-30% and 22.9-40% respectively was reported. While, as for the chest CT a reduction in the effective and CM dose of up to 25-32% and 23-30% respectively was revealed. Moreover, in the CT Coronary Angiography (CTCA) the results showed a reduction of the effective and CM dose of up to 13.5-94.8% and 20-60.7% respectively. Finally, with respect to the CT Pulmonary Angiography (CTPA) a reduction of the effective and CM dose of up to 27-63.6% and 22.9-58.3% respectively was mentioned.

KEY WORDS
Radiation; contrast medium; computed tomography

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Introduction

In recent years the rapid technological evolution of Computed Tomography (CT) has resulted in its widespread use for a broad range of indications. However, the widespread use of CT has raised concerns about the risks associated with radiation exposure and in particular the risk of induced cancer. Therefore, regarding the radiation dose all CT examinations should always be performed in accordance to the ALARA principle (As Low As Reasonably Achievable), while at the same time the image quality should be maintained diagnostically acceptable [1-4].

In addition, although the use of iodinated contrast media (CM) in CT procedures is essential for ensuring image quality, according to the literature an increase in radiation dose has been observed. Moreover, the application of high iodine concentration CM might increase the risk of contrast-induced nephropathy (CIN) and renal toxicity because of the high concentration and the high viscosity and osmolality. Consequently reducing contrast media dose is of particular importance for patients suffering from renal dysfunction [1-5].

For the mentioned reasons in order to be achieved diagnostically acceptable CT images with a minimum dose of radiation and contrast media, various approaches have been suggested. The most widespread method is the so-called "double-low" technique which refers to the combination of low tube voltage and low CM load with the use of an iterative reconstruction (IR) algorithm. By reducing the tube voltage the radiation exposure is reduced and the image noise is increased degrading the image quality. However, at low-kVp as the mean photon energy approaches the k-edge of iodine (33.2 keV) the iodine attenuation is increased compensating the image degradation and permitting the reduction of contrast media dose [6-8].

When selecting the optimum kVp tube-voltage one must consider: a) the generator power of the scanner, b) the patient's body size and c) the clinical task [9].

Generator Power - The voltage reduction leads to increased image noise due to insufficient photon flux especially in the cases of large sized patients. To compensate for the increased noise the total tube-current can be increased. However, there are CT scanners with low-power generators and consequently with limited tube-current. For this reason it is essential to be taken into account the tube-current limit of the scanner when selecting the optimal kVp tube-voltage [9].

Alternatively, the use of IR algorithms compensates for the image noise maintaining diagnostically acceptable image quality, and thereby smaller tube-current increases are permitted resulting in greater radiation dose reduction [9].

With the advent of the latest generations CT scanners, some authors have proposed the use of Dual Energy CTs (DECTs). Dual Energy CT discriminates X-ray photons into high-energy photons and low-energy photons making possible the reconstruction of virtual monochromatic images (VMIs) at discrete energy levels up to minimum 40 keV. As previously mentioned using low-energy photons close to the k-edge energy of iodine enables the increase of the CT number of contrast medium permitting injection of a lower dose of iodine. In addition, during Dual Source CT (DSCT) mode both X-ray tubes operate simultaneously increasing the total tube-current in order to maintain the image noise at the same level as that of the standard protocol. Based on these principles multiple approaches have been introduced: (1) dual source CT with two X-ray tubes operating at different (low or high) or the same tube voltage and two corresponding detectors, (2) spectral imaging with a single X-ray tube rapidly switching between low and high voltage, (3) dual-layer spectral detector CT with a single X-ray tube and a dual-layer detector which distinguishes a photon spectrum in a low and a high energy fraction [10].

Patient's Body Size - The patient's body size is of great importance when selecting kVp tube-voltage. Due to the increased noise at low-tube voltages the selection of an extremely low-tube voltage may result in the degradation of image quality and the appearance of artifacts, especially in the cases of patients with a high body mass index (BMI). Moreover, the attenuation of the photon beam may differ at different anatomical levels in the patient's scan range. As a result, a different tube voltage selection must be made at each anatomical level depending on the attenuation thickness. For this purpose Automated Tube Voltage Algorithms have been developed. The use of these algorithms is based on attenuation information obtained from the topogram [9].

Clinical Task - Furthermore, the selection of optimal kVp tube-voltage depends on the clinical task. For instance the detectability and evaluation of low-contrast solid organs is of great importance in abdominal CT. For this reason, the selection of an extremely low-tube voltage can result in the loss of the detectability of low contrast lesions due to the increased noise. On the contrary this dependence differs in chest imaging because of the much higher inherent contrast [9].

The purpose of this review article is to compare the various proposed approaches on "double-low" technique and determine the optimum protocol for each anatomical region (abdomen, chest, coronary arteries, pulmonary arteries). For this reason, a literature research was conducted to identify studies related to "double-low" technique protocols. The research was limited to studies published in English during the last seven years, in order to be ensured the use of the most recent CT scanning techniques. Twenty-four full-text articles were reviewed and categorized into different anatomical regions. In particular, studies related to CT abdomen, CT chest, CT coronary angiography and CT pulmonary angiography were reviewed. Four additional studies, involving different anatomical regions than those mentioned above, were reviewed and excluded due to their limited number. Pediatric and animal studies were excluded.

Discussion

Abdomen

Regarding abdominal CT examination using the "double-low" technique there are several studies in the literature [6, 9, 11-17]. According to these studies a protocol of low tube voltage (70, 80, 100 kV) in combination to low CM load with the use of an IR algorithm was implemented and compared to the conventional abdominal CT protocol (120 kV). The choice of both tube voltage and CM load was made according to the patients' BMI. For each study the subjective (scored overall image quality) and the objective (Signal to Noise Ratio, Contrast to Noise Ratio) characteristics of image quality, the $CTDI_{vol}$, the DLP, the effective radiation dose (ED) and the renal safety of reduced iodine dose were analyzed and compared to the corresponding elements of the standard protocol [6, 9, 11-17].

The results indicated that the majority of studies reported no inferior diagnostic acceptability and no statistical differences in objective diagnostic values of image quality compared to the conventional protocol. Nevertheless, some authors mentioned that the contrast of vessels and solid organs in the 80 kVp images was significantly higher compared to the 120 kVp images [6]. While, regarding the 70kVp protocol some others reported that the overall image quality was significantly better and the mean CT and Signal to Noise Ratio (SNR) values of the liver parenchyma were significantly higher [13-14]. However, many authors noted IR-artifacts due to the reduced photon flux for kVp tube-voltages of 70 and 80 especially in the cases of patients with BMI≥25 kg/m^2 [6, 9, 13, 15, 17].

Regarding the radiation and CM dose the majority of studies mentioned a reduction in the $CTDI_{vol}$ value and iodine load of up to 20-30% and 20-40% respectively compared to the conventional protocol (Table 1, 2) [6, 9, 16-17]. Nevertheless, some studies performed with the use of a Dual Source CT reported an increase in $CTDI_{vol}$ due to the total tube-current increase [13-14]. Some authors also reported that the presence of CM could increase the organ radiation doses up to 30% in contrast-enhanced abdominal CT [11-12].

However, these studies mentioned some limitations that mainly concern: 1) the small number of patients who participated in the studies, 2) the appearance of artifacts due to the reduced photon flux for kVp tube-voltages of 70 and 80, resulting in the limitation of the application of the "double-low" technique in patients with BMI≥25 kg/m^2, 3) the increase of the dose due to the total tube-current increase during the Dual Source CT mode [6, 9, 13-17].

According to the reported studies, despite the kVp reduction the higher attenuation of iodine results in increased contrast enhancement improving the diagnostic performance of CT urography, CT enterography and abdominal CT angiography. However, taking into account all the mentioned limitations the appropriate tube-voltage selection must be made so that there is an optimal trade-off between image quality and radiation dose. The combination of a tube-voltage adjusted via Automated Tube Voltage Algorithm and low CM load with the use of an IR algorithm would be preferable avoiding any limitations regarding patient size, tube current and loss of the detectability of low contrast lesions.

CHEST

There are few studies in the literature about the appli-

Table 1. Radiation Dose in abdominal CT

Study	Protocol	CTDIvol (mGy)	SSDE (mGy)	DLP (mGy*cm)	Effective dose (mSv)
Nagayama Y. et al	Study protocol	7.3 ± 1.3	10.7 ± 1.2	-	-
	Standard protocol	10.6 ± 1.4	15.8 ± 1.6	-	-
Miyoshi K. et al	Study protocol	AP : 12.4 PVP: 13.3, for body weight>55 kg EP: 12.5 AP: 11.0 EP: 11.2, for body weight<55 kg	-	-	-
	Standard protocol	AP: 11.8 PVP: 11.5, for body weight>55 kg EP: 11.6 AP: 10.9 EP: 10.9, for body weight<55 kg	-	-	-
Svensson A. et al	Study protocol	14 ± 4.7	17 ± 4.2	668 ± 244	10 ± 3.7
	Standard protocol	7.9 ± 1.7	9.8 ± 1.1	393 ± 107	5.9 ± 1.6
Kim S. Y. et al	Study protocol	9.95 ± 9.79	-	381.71 ± 269.06	5.73 ± 4.04
	Standard protocol	12.88 ± 8.34	-	562.16 ± 292.06	8.43 ± 4.38
Feng C. et al	Study protocol	8.64 ± 2.72	-	422.6 ± 149.40	6.34 ± 2.24
	Standard protocol	11.55 ± 3.95	-	568.3 ± 213.90	8.52 ± 3.21

**$CTDI_{vol}$=Computed Tomography Dose Index, SSDE=Size Specific Dose Estimate, DLP=Dose Length Product, AP=Arterial Phase, PVP=Portal Venous Phase, EP=Equilibrium Phase*

cation of "double-low" technique in chest CT.

Meng et al conducted a multicenter study involving 216 patients from 12 different hospitals. According to this study a comparison of four groups was performed: A: voltage, 120 kVp; iodine concentration, 350 mgI/mL; B: voltage, 100 kVp, iodine concentration, 350 mgI/mL; C: voltage, 120 kVp, iodine concentration, 270 mgI/mL; and D: voltage, 100 kVp, iodine concentration, 270 mgI/mL. In addition, Iterative Algorithms were applied to all four protocols. Among these groups there were no significant

Table 2. % CM Load reduction in abdominal CT			
Study	**Protocol**	**CM concentration**	**% CM load reduction**
Nagayama Y. et al	Study protocol	360 mgI/kg	40
	Standard protocol	600 mgI/kg	
Miyoshi K. et al	Study protocol	300mgI/kg	50
	Standard protocol	600 mgI/kg	
Svensson A. et al	Study protocol	250 mgI/kg or 300 mgI/kg depending on BMI	40-50
	Standard protocol	500 mgI/kg	
Kim S. Y. et al	Study protocol	240 mgI/mL	31.4
	Standard protocol	350 mgI/mL	
Feng C. et al	Study protocol	270 mgI/mL	22.9
	Standard protocol	350 mgI/mL	

differences in gender, age, height, weight and body mass index. Regarding the image quality the results of the 120 kV groups (A, C) were slightly better in comparison to the results of the 100 kV groups (B, D). While, regarding the effective dose the results indicated significant reduction of the effective dose up to 32% for the 100 kV groups (B: 4.1 ± 1.5 mSv, D: 3.4 ± 1.5 mSv) compared to the effective dose of the 120 kV groups (A: 5.0 ± 2.1 mSv, C: 5.0 ± 2.2 mSv). Consequently, the combination of low concentration contrast medium (270 mgI/mL) and low-tube-voltage (100 kVp) could reduce the radiation dose and simultaneously maintain diagnostically acceptable the image quality. However, there are some limitations such as the relatively small number of cases involving patients with a BMI between 18 and 28 [7].

Another relevant study is that of Eller et al according to which the standard protocol of chest CT [A: n=50; voltage, 120 kVp; iodine concentration, 350 mgI/mL, 16.1 g, 46 ml; Filtered Back-Projection (FBP) (B41,B70)] was compared to the protocol of group B [B: n=47; voltage, 100 kVp; iodine concentration, 350 mgI/mL, 11.3g, 32 ml; IR (I41,I70); n=15; voltage, 80 kVp; iodine concentration, 350 mgI/mL, 8.1 g, 23 ml; FBP (I41,I70)]. Automated Tube Voltage Algorithm was applied to group B resulting in the selection of 100 kV in 47 examinations and 80 kV in 15 examinations. The BMI for the standard group was 27 ± 6 kg/m^2, while the BMI for the study group was 21 ± 4kg/m^2 and 26 ± 4kg/m^2 for the 80 kV and the 100 kV respectively. From the results emerged that the study protocol provided equivalent objective and subjective image quality compared to the standard protocol. However, the image artifacts were slightly increased in 80 kV images. While, as for the effective dose the results indicated significant reduction of the effective dose up to 47% for the 80 kV examinations (1.9 ± 0.6 mSv) and 25% for the 100 kV examinations (2.7 ± 0.8 mSv) compared to the effective dose of the standard protocol (3.6 ± 1.0 mSv). In summary, using Automated Tube Voltage and IR algorithms the average contrast medium and radiation dose could be reduced by approximately one-third maintaining the image quality compared to the standard protocol [18].

There are also some studies which performed with the use of a phantom and came up with similar results

Table 3. Radiation Dose in CTCA

Study	Protocol	$CTDI_{vol}$ (mGy)	DLP (mGy*cm)	Effective dose (mSv)
Zhang H et al	Study protocol	-	A:120.01±13.44 B:165.71±14.18	1.68±0.67 2.32±0.70
	Standard protocol	-	167.14±14.64	2.34±0.62
Oda S et al	Study protocol	33.3±8.1	-	7.7±2.1
	Standard protocol	36.5±8.2	-	8.9±2.0
Feng R et al	Study protocol	1.58 ± 0.25	25.63±4.43	0.36 ± 0.06
	Standard protocol	1.59 ± 0.24	27.5 ± 5.5	0.38 ± 0.07
Jia C F et al	Study protocol	-	23.6 ± 3.1	0.3 ± 0.1
	Standard protocol	-	416.4 ± 2.9	5.8 ± 1.8
Zhao L et al	Study protocol	1.23±0.41	62.95±21.54	0.32±0.11
	Standard protocol	3.19±1.05	160.15±15.13	0.79±0.08
Huang X et al	Study protocol	128.73±37.81	-	1.80±0.53
	Standard protocol	132.66±38.36	-	1.83±0.51
Cha MJ et al	Study protocol	-	B:185.86 ± 33.99 C: 194.26 ± 38.75	B: 2.60 ± 0.48 C: 2.72 ± 0.54
	Standard protocol	-	255.94 ± 47.69	3.58 ± 0.67

**$CTDI_{vol}$=Computed Tomography Dose Index, DLP=Dose Length Product*

[19-20]. According to these studies for a medium-sized phantom a reduction of radiation dose up to 10%, 19% and 39% for 100 kVp, 80 kVp and 70 kVp respectively compared to the reference tube voltage 120 kVp can be achieved. Moreover, a reduction of contrast medium density up to 50% for a medium-sized phantom was also reported. However, these studies reported some limitations regarding larger patient sizes. For larger patient sizes there were technical limitations due to the required tube output in order to achieve comparable Contrast to Noise Ratio (CNR) levels to those using high tube voltages. In addition, as phantom studies they did not take into account the anatomical noise or the artifacts caused by breathing and pulsation. For this reason a clinical validation of the results is necessary [19-20].

From the cited studies a reduction of iodine dosage is possible by approximately one-third compared to the standard protocols. Regarding the optimum selection of kVp tube-voltage a tube-voltage adjusted via Automated Tube Voltage Algorithm would be preferable avoiding any limitations especially for larger patient sizes. While, the use of IR algorithms compensates for the increased image noise occurred due to tube voltage reduction. However, it needs further investigation in clinical practice due to the limited number of studies.

Table 4. % CM Load reduction in CTCA

Study	Protocol	CM concentration	% CM load reduction
Oda S et al	Study protocol	140 mgI/Kg	50%
	Standard protocol	280 mgI/Kg	
Jia C F et al	Study protocol	30 mL/300 mg I/mL	60.7%
	Standard protocol	65 -75 mL/300 mg I/mL	
Zhao L et al	Study protocol	40 ml /270 mgI/ml	51%
	Standard protocol	60 ml/ 370 mgI/ml	
Huang X et al	Study protocol	0.8 and 0.4 mL/kg- Half of 270 mgI/mL	50%
	Standard protocol	0.8 and 0.4 mL/kg- 270 mgI/mL	
Zhang H et al	Study protocol	A: 270 mgI/ml	21.27 % vs B 24.83% vs C
	Standard protocol	B: 350 mgI/ml C:370 mgI/ml	
Cha MJ et al	Study protocol	B:320 mgl/m-4 mL/s injection rate, C:320 mgl/m-5 mL/s injection rate	20%
	Standard protocol	400 mgl/m-4 mL/s injection rate	

CT Coronary Angiography

The Computed Tomography Coronary Angiography (CTCA) is preferred as an effective and non-invasive method for the diagnosis and screening of coronary arteries. For this purpose a conventional protocol of a tube voltage of 120 kVp or 100 kVp with standard FBP image reconstruction and of high iodine concentration is applied. However, in order to reduce radiation and CM dose many studies referring to the “double-low” technique were proposed [8, 21-26]. According to these studies a protocol of low tube voltage (70, 80, 100 kV) in combination to low CM load with the use of an IR algorithm was implemented and compared to the conventional CTCA protocols (100 or 120 kV). The majority of studies were conducted with the use of Dual Source Systems or Dual Layer Detector Systems [22-26]. For each study, the subjective and objective characteristics of image quality as well as the radiation dose were analyzed and compared to the corresponding elements of the standard protocols [8, 21-26].

In the majority of studies, the results showed a reduction in the effective and iodine dose of up to 13.5-94.8% and 20-60.7% respectively compared to the conventional protocols (Table 3, 4) [8, 21-26]. While, no significant differences in subjective and objective diagnostic values (SNR, CNR) of image quality were observed [8, 21-26].

However, the primary limitation of these studies is that they focus on a low weight population (BMI<28 kg/m^2 or average weight of 70 kg), which is not representative of the entire population. In addition, the patients with heart rate>72 bmp and previous iodine allergy are another exclusion criterion [8, 21-26].

According to the reported studies the use of a Dual Source System in combination with sophisticated algorithms (IR, Automated Tube Voltage Algorithm) has contributed significantly to the reduction of radiation and CM dose maintaining simultaneously the image quality in CTCA examinations. Moreover, the use of a Dual Source CT combined with IR and Automated Tube Voltage Algorithms could be an optimum solution eliminating any limitation regarding patient size for the reasons mentioned in the introduction. However, even in the cases of conventional CT scanners, the use of IR and Automated Tube Voltage Algorithms could positively contribute to the reduction of radiation and CM dose maintaining the image quality even in cases of large-size patients.

CT Pulmonary Angiography

Computed Tomography Pulmonary Angiography (CTPA) is recommended for the confirmation of pulmonary embolism (PE), since segmental and sub-segmental pulmonary artery filling defects can be displayed through this specific examination. Hu et al conducted a study involving 382 patients divided into two groups. A comparison between the double-low protocol (Group A) and the standard protocol (Group B) was performed. Group A was scanned with a tube voltage of 80 kVp, a CM concentration of 270 mgI/ml and an image reconstruction algorithm of 40% ASIR and 60% FBP. Whereas, Group B was scanned with a tube voltage of 120 kVp, a CM concentration of 350 mgI/ml and an image reconstruction algorithm of FBP. The results revealed no significant differences regarding the subjective image quality. However, a reduced quantitative image quality (SNR, CNR) was observed regarding the group A. While, as for the effective dose and the CM load a reduction of up to 63.6% and 22.9% respectively was reported. However, there are some limitations. First of all, the proposed protocol was applied to patients with BMI<30kg/m^2. Moreover, grade 5-6 pulmonary artery branches were not displayed in a small number of cases resulting in missed filling defects [27].

Another relevant study is that of Suntharalingam et al, in which 100 patients with a median BMI of 26.6 kg/m^2 underwent CTPA using a Dual-Source CT system equipped with automated exposure control. The patients divided into two groups and were scanned with the standard and the proposed protocol respectively. Group A was scanned with a tube voltage of 80 kVp, 25 ml CM of 350 mgI/ml concentration and an IR algorithm. While, Group B was scanned with a tube voltage of 100 kVp, 60 ml CM of 350 mgI/ml concentration and an IR algorithm. A comparison between the two groups was performed. The results indicated no significant differences regarding the subjective and objective diagnostic values (SNR, CNR) that specify image quality. While, as for the effective dose and the CM load a reduction of up to 71.8% and 58.3% respectively was observed [28].

Furthermore, Aldosari et al compared the results of 59 patients divided into three groups. Group A was scanned with a tube voltage of 100 kV, a pitch of 0.9 and a CM volume of 35-45 ml. Group B was scanned with a tube voltage of 120 kV, a pitch of 0.9 and a CM volume of 35-45 ml. Group C was scanned with a tube voltage of 120 kV, a pitch of 3.2 and a CM volume of 20-30 ml. According to the results there were no significant differences in image quality assessment among the three groups. Regarding the effective dose a reduction of up to 48% and 27% was achieved in low kVp protocol compared to Groups B and C respectively [29]. Similar results were also revealed according to the systematic review of Aldosari S and Sun Z [30]. However, there are some limitations such as the small number of participants. Moreover, due to the relative large body mass of the participants low kVp tube voltages of 70 and 80 were not used. Finally, only patients with confirmed pulmonary embolism were included, which could introduce bias in image analysis [29].

In conclusion, “double-low” technique is feasible in the diagnosis of pulmonary embolism with significant reduction in radiation dose while maintaining image quality. The combination of a tube voltage of 80 kV and low CM load with the use of IR algorithms could be preferable in cases of average-size patients. However, in cases of large-size patients a combination of a tube voltage of 100 kV and low CM load with the use of an IR algorithm could be the optimum choice.

Conclusion

According to the mentioned results "Double-Low" technique with the use of an IR algorithm is a very promising approach regarding the CT abdomen, CT chest, CTCA and CTPA. Nevertheless, the selection of the optimum protocol depends on the patient's body size, the generator power and the clinical task.

The implementation of the technique on the abdominal CT revealed a reduction in the $CTDI_{vol}$ and CM load of up to 20-30% and 22.9-40% respectively. While, regarding the chest CT a reduction in the effective and CM dose of up to 25-32% and 23-30% respectively was reported. However, it needs further investigation in clinical practice due to the limited number of studies. Moreover, in the CTCA a reduction of the effective and CM dose of up to 13.5-94.8% and 20-60.7% respectively was emerged. Finally, as for the CTPA a reduction of the effective and CM dose of up to 27-63.6% and 22.9-58.3% respectively was mentioned.

Nevertheless, the effectiveness of the technique should also be investigated in other CT protocols. **R**

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