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Computed tomography portography of patients with cirrhosis with normal body mass index

Comparison between low-tube-voltage CT with low contrast agent dose and conventional CT

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Abstract

This study is to investigate the computed tomography (CT) image quality of the low- tube-voltage protocol with low contrast agent dose.

CT portography was performed in 118 cirrhosis patients with body mass index (BMI) less than 25 kg/m^2 under 2 protocols: Protocol A, tube voltage of 90 kVp/395 mAs and contrast agent dosage of 1.2 mL/kg, and, Protocol B, tube voltage of 120 kVp/200 mAs and contrast agent dosage of 1.5 mL/kg.

The number of patients in each protocol was 59. The CT value noise, signal-to-noise ratio (SNR), and contrast-to-noise ratio (CNR) in portal veins was comparatively analyzed between the 2 protocols. The subjective image quality was further assessed on 5-point scales. Radiation dose was also recorded and statistical analysis was performed.

The CT value, CNR, and SNR of the images were higher at 90 kVp than those at 120 kVp ($P < .05$). There was no significant difference in image noise between the 2 protocols ($P > .05$). The CT dose index volume, dose-length product, and effective dose at 90 kVp were 18.2%, 16.0%, and 16.0% less than that at 120 kVp, respectively. There was no difference in image quality score between the 2 protocols ($P > .05$). The average amount of contrast agent was decreased by 17.8% when the 90 kVp protocol was used.

CT portography at 90 kVp combined with low-dosage contrast agent leads to a significant reduction in radiation dose and improved SNR and CNR, without deterioration of image quality.

Abbreviations: BMI = body mass index, CNR = contrast-to-noise ratio, CTDIvol = CT dose index volume, DLP = dose length product, EBW = extended brilliance workspace, ED = effective dose, MIP = maximum intensity projection, ROI = region-of-interest, ROIL = liver in ROI, ROIP = portal vein in ROI, SD = standard deviation, SL = scan length, SNR = signal-to-noise ratio, VRT = volume-rendering technique.

Keywords: computed tomography, image quality, low kVp, radiation dose

1. Introduction

Portal vein anatomy is very important for the treatment of liver diseases, such as intervention of portal hypertension, liver tumor resection and preoperative assessment for tumor resection.[1–6] Understanding the portal vein tributaries and collateral circulation situation provides reliable assistance to the clinical treatment of liver diseases.[1–6] However, the contrast of portal vein with the surrounding tissue is poor. In order to improve the image quality, some researchers[3,7] increased the amount of contrast agent by using a high concentration or injection rate in the conventional computed tomography (CT) imaging for portal vein. However, this would increase the probability of side effects of the contrast agent.[3,7] In addition, multi-phase scan is often applied for abdominal scans, thus causing more radiation damage to patients. The development of low-kV technology in the chest, heart and abdominal arteries imaging has made great progress, in which the radiation dose is significantly lower than that in the conventional CT scanning.[8–11] The purpose of the present study was to prospectively evaluate whether low amount of contrast agent (1.2 mL/kg) with low tube voltage (90 kVp) and high mAs (395 mAs) could reduce the radiation dose without decreasing the image quality in CT portography.

2. Materials and methods

2.1. Patients

From March 2016 to June 2016, a total of 118 cirrhotic patients were enrolled in this study. All patients were at the decompensation period of liver cirrhosis. They were randomly divided into 2

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SL, HS and JF contributed equally to the study.

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groups according to the scanning tube voltage, with 59 cases in each group. The 90 kV group included 48 males and 11 females, and their ages ranged from 25 to 73 years old with a mean age of 54.1 ± 12.4 years old. The 120 kV group included 46 males and 13 females, and their ages ranged from 20 to 78 years old with a mean age of 53.2 ± 11.0 years old. Body mass indexes (BMI) of all patients were less than 25 kg/m^2.[12,13] Prior written and informed consent was obtained from every patient and the study was approved by the ethics review board of Qianfoshan Hospital Affiliated to Shandong University.

2.2. CT technique

Multiple-phase CT scanning was performed using a 16-slice spiral CT scanner (Brilliance, Philips Healthcare, The Netherlands). All patients were positioned supine, with their feet first on the scanning table. The scanning range was from the top of the diaphragm to the lower edge of the liver. Two protocols were used: Protocol A, 90 kVp/395mAs, and Protocol B, 120 kVp/200 mAs. The pitch values of Protocols A and B were 0.813 and 0.938, respectively, which were the machine default. The other parameters used in the scan and reconstruction were the same in the 2 protocols. These parameters included: collimation 16 × 1.5 mm, reconstruction section thickness 0.625 mm, reconstruction interval 0.625 mm, field of view 350 mm, matrix 512 × 512, 2.0 mm thin slice thickness of portal venous phase image and 1.0 mm slice interval, window width 350 HU and window level 50 HU. The scan data was transferred to the post-processing Extended Brilliance Workspace (EBW) work station (Philips Healthcare, The Netherlands) and then the values were measured. The contrast agent (300 mgI/mL; Iohexol, Taizhou, China) was injected through the right antecubital vein via 18-gauge needle by power injector. The dosages for Protocols A and B were 1.2 and 1.5 mL/kg, respectively, and the rate was 2.8 to 3.0 mL/s. The delay time of portal phase was set at 50 seconds after injection.

2.3. Image processing and analysis

A radiologist with 7 years of experience in CT examinations measured the CT value and image noise within a 50 ± 1 mm^2 circular region-of-interest (ROI) in the liver, portal vein and abdominal aorta. The CT value of liver in ROI (ROI_L) was measured at the level of portal vein in three different parts, including the right anterior lobe, right posterior lobe and left liver lobe. Blood vessels and prominent artifacts in parenchymal density would be avoided carefully. The CT value of portal vein in ROI (ROI_P) of 3 consecutive sections from the portal confluence down to the portal vein was measured. In the meantime, the abdominal aorta standard deviation (SD_N) at the same level was measured as the noise value. The ROI_L was recorded as the mean of 3 ROI readings placed in the parenchymal, and the ROI_P and SD_N were calculated in the same way. The signal-to-noise ratio of the liver parenchyma (SNR) was calculated as follows: $SNR = ROI_L/SD_N$. The portal vein-to-liver contrast-to-noise ratio (CNR) was calculated using the following formula: $CNR = (ROI_P\text{-}ROI_L)/SD_N$.

For qualitative analysis, 2 radiologists with 7 years of experience in abdominal CT independently performed the blinded qualitative analysis of CT images obtained with each protocol during the portal venous phase. The images of axial, maximum intensity projection (MIP), and volume-rendering technique (VRT) were used for evaluation. Image quality was rated on a 5-point scale[14,15]: the main portal vein could be clearly shown; the left and right branches of portal vein were indicated well; the portal vein branches of liver lobe could be observed clearly; the portal vein branches of segment were clearly visualized; the portal vein branches of sub-segment were clearly visualized.

2.4. Measurement of radiation dose

The radiation doses of Protocols A and B were calculated, respectively. The CT dose index volume (CTDIvol, unit: mGy) and dose length product (DLP, unit: mGy cm), which were provided by the CT scanner, were recorded at the portal phase for each patient. The effective dose (ED, unit: mSv) was calculated as follows: $ED = DLP \times \kappa$, where κ is the conversion factor, using the European quality standard Guide CT average of 0.015 (mSv/mGy cm).

2.5. Statistical analysis

Statistical analysis was performed with the statistical software SPSS 19.0 (SPSS Inc, Chicago, IL). All numeric values were reported as mean ± standard deviation (SD). To compare the ROI_L, ROI_P, SD_N, CTDIvol, DLP, ED, SNR, CNR, scan length (SL), the image scores, and the amounts of contrast agent between Protocol A and Protocol B, independent sample *t* test was used. A *P*-value <.05 was considered as statistically significant. The inter-observer variability was estimated by the Cohen kappa test. The *k* values indicated poor (<0.40), moderate (0.41–0.60), good (0.61–0.80), and excellent (0.81–1.00) agreements, respectively.

3. Results

3.1. Patient demographics

There was no significant difference in the age, height, weight, and BMI of the included patients (Table 1).

3.2. Image quality

The ROI_L ROI_P, SD_N, SNR, and CNR were analyzed and compared between 2 protocols. The 90 kVp group showed significantly higher CT value than120 kVp group, in the liver and portal vein (both $P = .001$; Table 2, Fig. 1). The mean CT values of ROI_L and ROI_P in the images of 90 kVp group increased by 17.8, and 24.1%, respectively, compared to those of the 120 kVp group. The SD_N of the 90 kVp group was 16.3 ± 9.2, while that of the 120 kVp group was 14.3 ± 2.3. There was no statistical significance in SD_N between 90 kVp, and 120 kVp group ($P = .053$, Table 2). SNR and CNR in 90 kVp group were significantly higher than those in 120 kVp group ($P = .015$, .001; Table 2, Fig. 1). SL of the 90 and 120 kVp groups were 23.2 ± 2.4 and 23.2 ± 2.5, respectively, and there was no statistical significance ($P = .511$, Table 2).

Table 1

Clinical data of patients.

Parameter	90 kVp (n = 59)	120 kVp (n = 59)	*T* value	*P* value
Age, y	54.1 ± 12.4	53.2 ± 11.0	−0.407	.341
Height, m	1.68 ± 0.07	1.67 ± 0.07	−0.623	.225
Weight, kg	62.5 ± 7.3	60.8 ± 8.1	−1.231	.121
BMI, kg/m^2	22.1 ± 1.9	21.7 ± 2.2	−1.137	.153

BMI = body mass index.

Table 2

Measurements of the 2 protocols.

Parameter	90 kVp (n=59)	120 kVp (n=59)	*T* value	*P* value
ROI_L (HU)	101.1±16.6	83.6±13.9	−6.191	.001
ROI_P (HU)	186.9±29.3	141.8±26.9	−8.696	.001
SNR	6.9±2.3	6.1±1.6	−2.401	.015
CNR	5.7±2.0	4.2±1.6	−4.398	.001
SD_N	16.3±9.2	14.3±2.3	−1.633	.053
Score	4.6±0.5	4.5±0.5	−0.733	.139
SL, cm	23.2±2.4	23.2±2.5	0.038	.511

CNR=contrast-to-noise ratio, ROI_L=mean CT value of liver, ROI_P=mean CT number of portal vein, SNR=signal-to-noise ratio, SD_N=standard deviation of aorta, SL=scan length.

The subjective image quality score had no significant difference between 2 groups (P=.139; Table 2, Fig. 2). Compared with 120 kVp group, the image quality in 90 kVp group was not obviously decreased. Moreover, the *k*-value of inter-observer agreement for the subjective image quality was 0.74, indicating good inter-observer agreement between the 2 observers.

3.3. Radiation dose and volume of contrast agent

As shown in Table 3, CTDIvol (12.4±5.0 vs15.2±6.8, P=.006), DLP (322.1±28.0 vs 381.0±35.1, P=.001), ED (4.8±0.4 vs 5.7±0.5, P=.001), between 90 and 120 kVp groups all had statistical significance. Compared with those in 120 kVp group, and the values of CTDIvol, DLP, and ED in 90 kVp group decreased by 18.2%, 16.0%, and 16.0%, respectively.

The volume of contrast agent in the 90 kVp protocol (75.0± 8.7 mL) was 17.8% lower than that in the 120 kVp protocol (91.2±12.2 mL), and the difference had statistical significance (P=.001, Table 4).

4. Discussion

The imaging quality of portal vein by CT depends on the contrast between portal veins and surrounding tissues.[2,16] A better contrast between the portal vein and liver parenchyma will lead to a better image quality.[2,16] In the past, scholars used to increase the dosage of contrast agent or the injection rate of contrast agent to enhance the density of the portal vein, thus improving the image quality of portal veins.[3,7] However, excessive use of contrast agents and increasing injection rate would cause more serious side effects.[17–21] Researches showed that low kVp scanner could significantly improve the CT values of blood vessels without increasing the amount of contrast agent, so that the radiation dose received by patients could be reduced.[22–24] In addition, the mAs should be increased appropriately in order to ensure the image quality.[25] Therefore, low kVp and high mAs scan mode also achieved good clinical application in the CT examination of some organs. Nakayama et al [26] showed that when tube voltages decreased from 120 to 90 kVp and tube currents increased, there was no significant difference in the low contrast resolution capability and the radiation dose reduced by 35%. Nakayama et al [11] subsequently applied 120 kVp, 300 mAs, and 90 kVp, 300 mAs in clinical examination of patients, and the results showed that the SNR of images decreased, the radiation dose reduced by 56.8% and the image noise increased. Marin et al [27] applied 80 kVp, 540 mAs and used a new image reconstruction algorithm for image analysis in late arterial phase. The image noise was effectively reduced and the obtained images met the needs of clinical diagnosis, as well as the radiation dose reduced by 71%. In this study, the tube voltage dropped from 120 to 90 kVp, while the tube current was increased from 200 to 395 mAs. The results showed that the image noise had no significant difference between 120 and 90 kVp when applied in the patients with BMI less than 25 kg/m^2. CTDIvol, DLP, and ED at 90 kVp were lower than those at 120 kVp, and decreased by 18.2, 16.0, and 16%, respectively. SNR and CNR of the images at 90 kVp were higher than those at 120 kVp, suggesting 90 kVp is more conducive to display the portal vein.

In this study, the amount of radiation dose reduction was less than that in the studies of Nakayama et al [11] or Marin et al [27]. The tube current time in this study was 395 mAs, while that in Nakayama's research was 300 mAs. In Marin's research, the applied tube voltage was 80 kVp, while that was 90 kVp in this study. As the tube current time or tube voltage in this study was

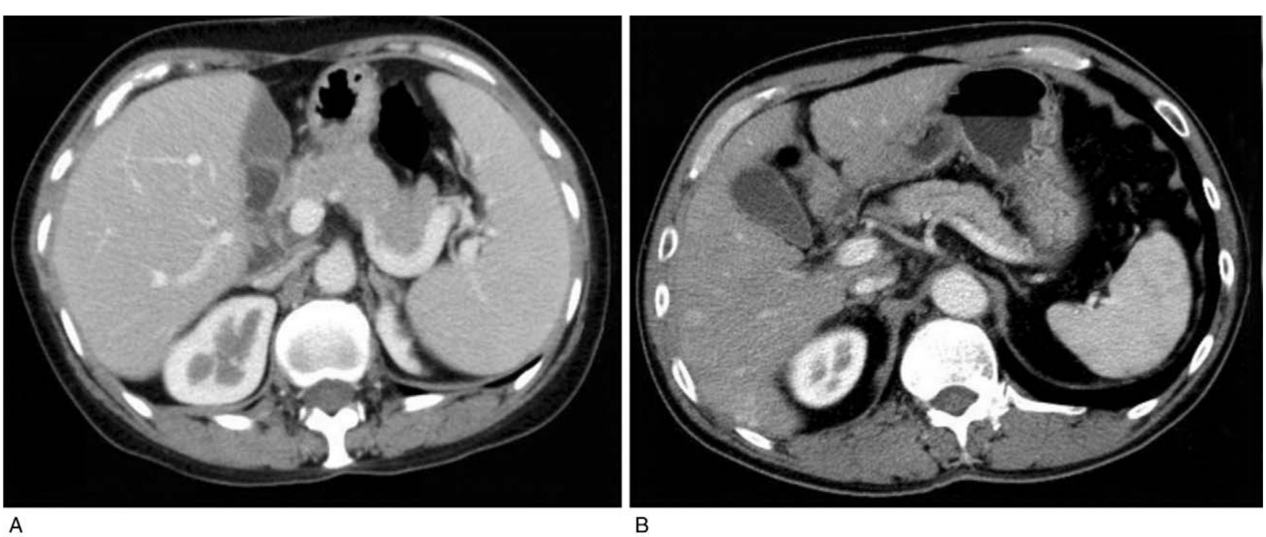

Figure 1. (A) Image of a 46-year-old woman obtained with the protocol of 90 kVp. ROI_L=99.2HU, ROI_P=207.3HU, SNR=6.4, CNR=5.8, SD_N=16.2. (B) Image of a 52-year-old man obtained with the protocol+ of 120 kVp. ROI_L=78.2HU, ROI_P=132.8HU, SNR=6.1, CNR=4.1, SD_N=15.8.

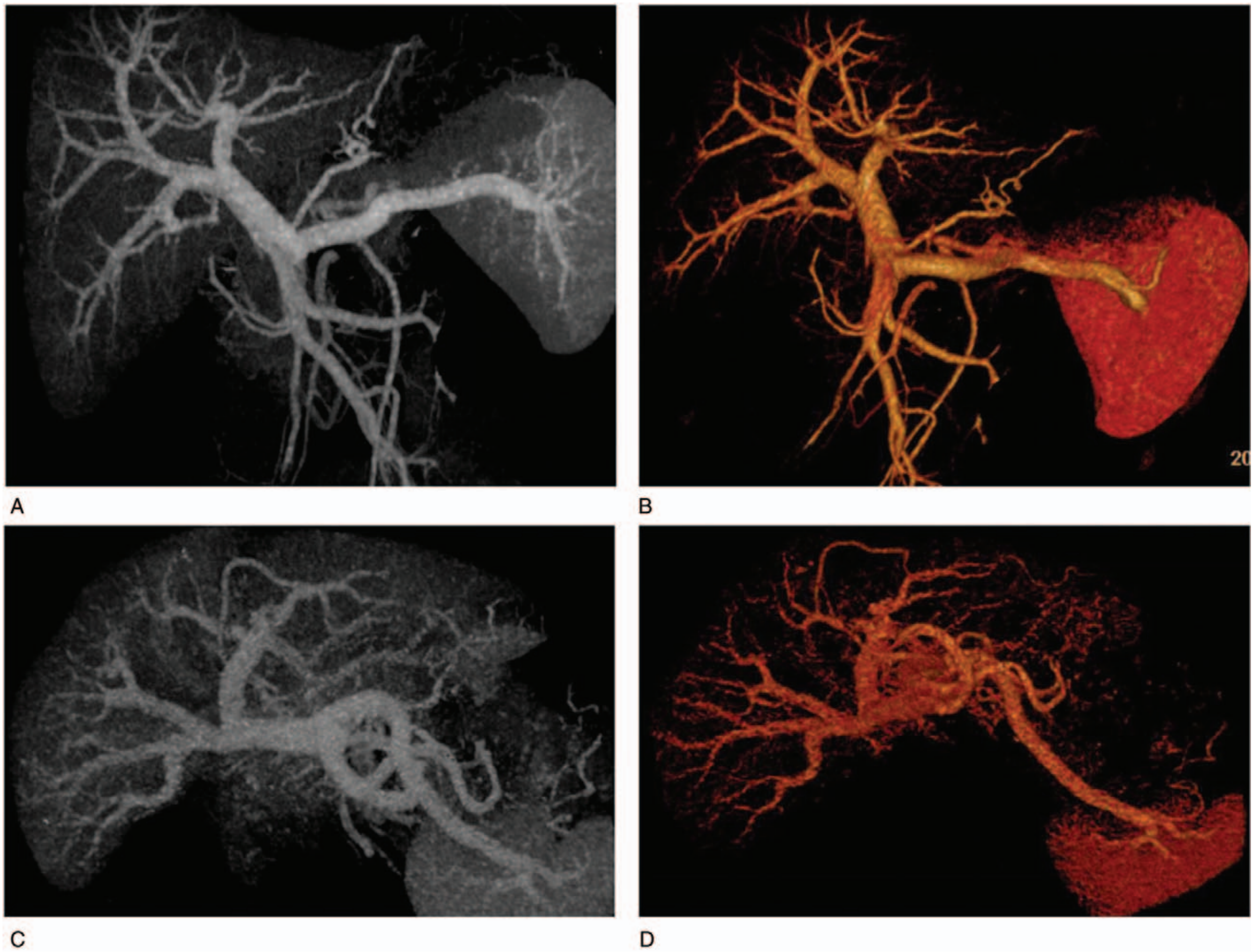

Figure 2. (A) MIP and (B) VRT image of a 55-year-old woman obtained with the protocol of 90 kVp (the subjective score of 5). (C) MIP and (D) VRT image of a 49-year-old man obtained with 120 kVp (the subjective score of 5). Both of the portal vein branches of sub-segment were clearly visualized.

lower than those in Nakayama's research or Marin's research, the amount of reduced radiation dose was less.

The SD_N in this study did not increase significantly compared to conventional scanning, but SNR increased. However, in the previous study,[11,28] SD_N raised and SNR decreased. This might because the selected patients in this study had BMI less than 25 kg/m^2. Therefore, the increased tube current led to good control of image noise, and the increased CT values of liver with low tube voltage in the portal phase increased the SNR. Nakaura et al[29] used a 64-slice Philip CT scanner with automatically tube current regulation technology to examine a group of subjects with body weight less than 70 kg. The 80 and 120 kVp tube voltages were used, respectively. The image noise of 80 kVp was higher than that of 120 kVp, and in some subjects the window width had to be adjusted in the 80 kVp images. This study did not adjust the window width in the scanning application.

The CT plays a very important role in the assessment of portal vein diseases. However, the administration of high dosage contrast agent always yields high vascular attenuation in the large and tiny vessels.[30] Particularly in the clinical practice, application of high dosage contrast agent might increase the risk of contrast-induced nephropathy. Application of low dosage contrast agent is essential to reduce the iodine burden in kidneys. Also, given the fact that CT values of organs with contrast agent would be increased significantly at low tube voltage scanning,[10] the dosage of contrast agent was decreased from 1.5 to 1.2 mL/kg in this study. The results showed that the CT values of portal vein and liver parenchyma did not decrease, but significantly increased. The SNR of liver and portal vein also increased, but the average amount of contrast agent reduced by 17.8%. These

Table 3

Radiation dose analysis.

Parameter	90 kVp (n=59)	120 kVp (n=59)	*T* value	*P* value
CTDIvol, mGy	12.4±5.0	15.2±6.8	17.321	.006
DLP, mGy cm	322.1±28.0	381.0±35.1	10.083	.001
ED, mSv	4.8±0.4	5.7±0.5	10.083	.001

CTDIvol=CT dose index volume, DLP=dose length product, ED=effective dose.

Table 4

The volume of contrast agent analysis.

Parameter	Mean volume, mL	*T* value	*P* value
90 kVp (n=59)	75.0±8.7	−8.279	.001
120 kVp (n=59)	91.2±12.2		

findings indicate that our protocol is a promising approach, which can significantly reduce the radiation dose while provide superior diagnostic quality images. This protocol should be recommended in the portal vein examination.

However, there were some limitations in this study. Firstly, the selected subjects had normal weight (BMI < 25 kg/m^2), but those subjects with a BMI greater than 25 kg/m^2 was not included. This is because that the X-ray penetration ability is weakened with the increase of BMI. When using low tube voltage (90 kVp in this study), the image quality of patients with BMI > 25 kg/m^2 will be impacted. Secondly, the amount of contrast agent could be further reduced. Thirdly, the amount of radiation dose reduction was less than the reported ones.[11,27]

In conclusion, limited to the lower BMI patients, CT portography at 90 kVp with low dosage of contrast agent results in a significant reduction in radiation dose and significantly improves SNR and CNR, without impairing the image quality.

Author contributions

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Resources: Huaqiang Sheng, Hao Shi, Wei Li.
Validation: Hongjun Sun.
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Writing – review & editing: Jingli Fan, Jingzhen He, Hongjun Sun.

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