

Significance of an Advanced Image-Based **Virtual Monoenergetic Reconstruction of Dual** Source Dual-Energy CT Data at Low keV **Increases Image Quality for Portal Vein System** of Pancreatic Cancer Patients

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How to cite this paper: Zhuo, S.Q., Zeng, S.H., Yu, J.P. and Liu, L.Z. (2018) Significance of an Advanced Image-Based Virtual Monoenergetic Reconstruction of Dual Source Dual-Energy CT Data at Low keV Increases Image Quality for Portal Vein System of Pancreatic Cancer Patients. Journal of Cancer Therapy, 9, 827-837. https://doi.org/10.4236/jct.2018.910068

Received: October 9, 2018 Accepted: October 26, 2018 Published: October 29, 2018

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Abstract

Purpose: To explore the significance of dual-source computed tomography (DECT) virtual monoenergetic reconstructions technology in improving image quality for portal vein system of pancreatic cancer patients. Materials and methods: 47 patients with clinically suspected pancreatic cancer (all confirmed by pathology) were collected. Routine plain scan was performed with Siemens Force dual-source dual-energy CT followed by 3 scans respectively carried out in arterial phase, portal phase and delayed phase. Traditional virtual monoenergetic reconstructions (Mono_E) and new generation of virtual monoenergetic reconstructions (Mono+) were respectively performed on portal vein images to obtain virtual single energy images including Mono_ E70 keV, Mono_E 55 keV and Mono+ 70 keV and Mono+ 55 keV. The signal-to-noise ratio (SNR) and noise of portal vein, normal pancreatic tissues and pancreatic lesions of 100 kV, Mono E and Mono+ images were compared. In addition, the contrast noise ratio of portal vein and lesions as well as pancreatic tissues and lesions (CNR PV, CNRtumor) were also compared. At the same time, two imaging physicians with rich clinical experiences read the films and scored the images of each group by using the 5-point scoring method. Results: Mono+ 55 keV images including SNRpv, SNRpanc, SNRtumor, Noise, CNRpv, CNRtumor were statistically different from 100 KV images and Mono_E images (P < 0.05). As for the subjective score, Mono+ 55 keV image score also had the highest score, which had statistical significance

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(P < 0.05). The results showed that Mono+ 55 keV images had the best quality. **Conclusion:** The new generation of virtual Mono+ post-treatment can reduce image noise. Low energy Mono+ images can improve the contrast between pancreatic cancer lesions and portal of pancreatic cancer patients.

Keywords

Dual-Source, Virtual Monoenergetic Reconstructions, Computed Tomography, Pancreatic Tumors, Portal Vein System, CT Angiography, Image Quality

1. Introduction

Pancreatic cancer is a fatal malignant tumor, rarely found in the early stage. It is called "the king of cancer" because of its low resection rate, easy recurrence and strong invasiveness [1]. For patients diagnosed with pancreatic cancer, radical resection is the only effective way to achieve long-term survival. The preoperative localization diagnosis and resectability evaluation of pancreatic tumors is one of the hot spots and difficulties in abdominal surgery. Imaging plays an important role in the diagnosis, staging and prognosis of pancreatic cancer. The pancreas is closely related to peripheral blood vessels such as abdominal aorta, portal vein, inferior vena cava, superior mesenteric artery and vein, and splenic artery and vein. In preoperative evaluation of pancreatic cancer, it is very important to clarify the relationship between tumor and peripheral blood vessels as well as the scope and extent of invasion to blood vessels. The purpose of this study is to explore the advantages of the new generation of virtual single-energy post-treatment technology (Mono+) of dual-source dual-energy CT compared with 100 KV mixed-energy images and traditional virtual single-energy post-treatment technology (Mono_E) and its significance in improving the imaging quality of portal vein system of pancreatic cancer patients.

2 .Materials and Methods

2.1. General Data

47 patients with pancreatic cancer from June 2017 to April 2018 were retrospectively collected, including 32 males and 15 females, aged from 33 years old to 79 years old, with an average age of 58.19 ± 10.36 years and an average weight of 59.02 ± 7.89 kg. Case inclusion criteria: 1) All the patients with pancreatic cancer confirmed by pathological results; 2) All the patients were initially diagnosed; 3) the patients were conscious and able to cooperate with the examination. 4) There was no statistical difference in weight. Exclusion criteria: 1) The patients have hepatic and renal insufficiency; 2) The patients have contraindication of iodinated contrast agent; 3) The patients have serious cardiac dysfunction and other diseases. This study was approved by the local ethics committee.

2.2. Inspection Methods

All study examinations were performed on the same third-generation dual-source CT scanner (SOMATOM Force, Siemens Healthcare, Forchheim, Germany); the U.S. MEDRAD Stellant CT special high pressure syringe was used. The contrast agent was 350 mg/ml nonionic iodine-containing contrast agent. The dosage was 1.5 ml/kg body weight and the bolus injection rate was 4 ml/s. 20 ml saline was injected at the same speed to test the patency of blood vessels before bolus injection of contrast agent, and 20 ml saline was injected for washing after bolus injection of contrast agent. All patients underwent routine plain scan, arterial scan, portal scan and delayed scan. In the arterial phase, the contrast bolus intelligent tracking technique was used. The tracking point was set at 2 cm below the diaphragm of abdominal aorta. The ROI area was about 1 mm² and the trigger threshold was 100 Hu. The arterial phase scan was started 7 seconds after the enhancement of the region of interest reached the threshold. The scanning range was from the diaphragmatic roof to the bifurcation of the abdominal aorta, and the scanning time is about 3 seconds. The portal phase scan was triggered 20 seconds after the arterial phase was completed, and the delayed phase trigger scan was 3 minutes after the contrast agent injection. During the portal vein phase, double-energy scan was used. The A and B bulb tube were started. The scan parameters: care dose 4d tube voltage and tube current intelligent modulation technology was used. CARE Dose4D tube voltage and current intelligent control technology was adopted. The reference tube voltage/tube current of the A and B bulb tube were: 100 kV/ref250 mAs, Sn150 KV/ref125 mAs. The bulb tube rotation speed was 0.5 second, and pitch was 1; collimation: $2 \times 192 \times 0.6$ mm; thickness slice: 1 mm.

2.3. Image Reconstructions

The three groups of images, group A, B, and M obtained during portal phase through dual-energy scan respectively represent 100 KV images, Sn150 kV images, and linear fusion images of the previous two. Workstations that transmit image A and B implement post-treatment by using the "dual energy" function module in Syngo.vi software. Two groups of images, group A and group B, were selected for nonlinear fusion by Mono_E and Mono+ to obtain four groups of simulated single energy images including Mono_E 70 keV, Mono E55 keV, Mono+ 70 keV and Mono+ 55 keV respectively. The "blood vessel" function module in Syngo.via VB20 software was used to perform three-dimensional reconstruction on the above four groups of simulated single energy images and 100 KV images to obtain volume rendering (VRT) images and maximum intensity projection (MIP) images.

2.4. Image Analysis and Measurement

Subjective evaluation: Syngo.via VB20 software was used for film reading in Simens workstation, and two senior imaging diagnostic physicians used double-blind method to carry out subjective evaluation on the cross-sectional images, VRT and MIP images of the above five groups of images respectively. In case of different opinions, consensus would be reached through joint review and negotiation. The window width was 400 Hu and the window level was 40 Hu. The evaluation contents included main portal vein, portal vein and its branches, pancreatic tissue and tumor tissue. Image quality evaluation criteria included: image noise, resolution, contrast, definition, artifact, focus contour and tissue edge display. 5-point evaluation was adopted: 1 point: the image quality is very poor and cannot be used for evaluation at all (the image noise is very high; the artifact is extremely significant; the spatial or contrast resolution is completely distorted, and the edge definition is very poor); 2 points: the image quality is poor, and can basically be used for evaluation (image noise is high; the artifact is obvious; spatial or contrast resolution is distorted, and edge definition is poor); 3 points: the image quality is general and can be tolerated, but is affected by appropriate amount of noise, artifacts and image distortion; 4 points: the image quality is good. The noise, artifact and image distortion does not affect the clinical diagnosis; 5 points: the image quality is very good. There is low noise, good contrast, no artifact and no image distortion, which completely meets the clinical diagnostic requirements.

Objective evaluation: Syngo.via VB20 software "MM Basic Comparison" was used to read the function module. At the same time, the above four groups of simulated unipolar images and 100 KV images were opened to measure the background noise of the images and the CT values and standard deviation of portal vein, normal pancreatic tissue, and tumor tissue. Measurement position: five groups of images were selected at the same level. ROI was placed in the air in front of the images, in the center of the portal vein, in the normal pancreatic tissue and in the tumor parenchyma. ROI was about 1 mm³. Each part was measured 3 times and the average value was taken of the 3 times of measurement (**Figure 1**). The signal-to-noise ratio (SNR) of the portal vein, normal pancreas and tumor, and the contrast noise ratio of portal vein and tumor were calculated. The calculation formula was: SNR = ROI/SD, $CNR_{pv} = (ROI_{pv} - ROI_{panc})/SD_{air}$, $CNR_{tumor} = (ROI_{panc} - ROI_{tumor})/SD_{air}$ [2].

2.5. Statistical Analysis

The measurement data of each group were expressed by mean \pm standard deviation. SPSS20 software was used for statistical processing. The measurement data, calculated values and subjective scores were tested for normality and homogeneity of variance. If the conditions were met, the paired t test was used. If the conditions were not met, the nonparametric Wilcoxon sign rank sum test was used. P \leq 0.05 indicated that the difference was statistically significant. The consistency of the image scores of the two radiologists was analyzed by weighted Kappa. Kappa > 0.75 indicated good consistency; $40 \leq$ Kappa \leq 0.75 indicated relatively good consistency; Kappa < 0.40 indicated poor consistency [3].



Figure 1. The ROI was placed in portal vein, normal pancreatic tissue, tumor tissue and air to measure CT value and standard deviation.

3. Results

All 47 subjects successfully completed multi-phase enhanced CT scan of the upper abdomen without any contrast agent allergy, and all of them were able to cooperate well with the examination. All the cases were confirmed by pathology as pancreatic cancer, including 25 cases of pancreatic head uncinate process cancer and 22 cases of pancreatic body and tail cancer. The signal-to-noise ratio (SNR) of portal vein, normal pancreas and tumor, the contrast noise ratio measurement data and statistical results of portal vein and tumor of the five groups of images were shown in Table 1, and the subjective scoring results of image quality were shown in Table 2.

3.1. Analysis of Statistical Results

Regarding to comparison of new generation of virtual monoenergetic reconstructions (Mono+) images with traditional virtual monoenergetic reconstructions (Mono_E) images and 100 KV images, portal vein signal-to-noise ratio (SNR PV): the comparison among Mono+ 70 keV, Mono+ 55 keV, Mono E 70 ke and 100 KV images had no statistical difference (P > 0.05). Mono_E 55 keV images had the lowest signal-to-noise ratio (P < 0.05); pancreatic signal-to-noise ratio (SNRpanc): according to the comparison among Mono+ 70 keV, Mono+ 55 keV, Mono_E 70 keV and 100 KV images, Mono+ 55 keV images had the highest signal-to-noise ratio, but there was no statistical difference (P > 0.05); Mono_E 55 keV image had the lowest signal-to-noise ratio (P < 0.05); tumor signal-to-noise ratio (SNR tumor): according to the comparison among Mono+ 70 keV, Mono+ 55 keV, Mono_E 70 keV and 100 KV images, Mono+ 55 keV images had the highest signal-to-noise ratio, but there was no statistical difference (P > 0.05); Mono E 55 keV images had the lowest signal-to-noise ratio (P < 0.05); noise: there were statistical differences among the five groups (P < 0.05), among which Mono+ 70 keV images and Mono+ 55 keV images had the lowest noise and Mono_E 55 keV images had the highest noise; portal vein contrast noise ratio (CNR PV) and tumor contrast noise ratio (CNR tumor): Mono+ 55 keV images had the highest contrast noise ratio which was significantly different from that of the first 4 groups of images (P < 0.05).

	100 kV	Mono E70 keV	Mono E55 keV	Mono+ 70 keV	Mono+ 55 keV
SNRpv	8.17 ± 1.68	8.08 ± 1.89	5.30 ± 1.34	8.34 ± 2.15	8.08 ± 1.86
SNRpanc	4.89 ± 1.18	5.13 ± 1.22	3.16 ± 0.82	5.21 ± 1.17	5.39 ± 1.26
SNRtumor	2.41 ± 0.86	2.77 ± 1.01	1.66 ± 0.63	2.82 ± 1.00	2.86 ± 1.13
Noise	12.1 ± 2.19	10.43 ± 1.98	22.89 ± 4.23	9.85 ± 1.82	9.87 ± 1.70
CNRpv	9.33 ± 3.43	10.20 ± 3.19	7.85 ± 2.90	10.58 ± 3.40	18.16 ± 5.32
CNRtumor	6.70 ± 2.88	6.18 ± 3.23	4.56 ± 2.30	6.51 ± 3.51	10.43 ± 5.63

Table 1. 5 Statistical results of measurement data of five image groups $(x \pm s)$.

Table 2. Subjective evaluation results of quality of five image groups $(x \pm s)$.

	100 kV	Mono_E 70 keV	Mono_E 55 keV	Mono+ 70 keV	Mono+ 55 keV
Portal vein display	3.58 ± 0.52	3.53 ± 0.51	2.65 ± 0.55	3.77 ± 0.60	4.47 ± 0.56
Tumor contour	3.00 ± 0.29	3.03 ± 0.36	1.70 ± 0.52	3.19 ± 0.51	3.97 ± 0.54
Image quality	3.23 ± 0.37	3.29 ± 0.36	1.70 ± 0.53	3.51 ± 0.40	4.18 ± 0.42

3.2. Analysis of Subjective Evaluation

The subjective evaluation results of 5 groups of images showed that: Mono+ 70 keV, Mono_E 70 keV and 100 KV images had no significant difference in portal vein, tumor contour and overall image quality (P > 0.05); Mono_E 55 keV images had the lowest subjective score which was significantly different from that of other 4 groups (P < 0.05); Mono+ 55 keV images had the highest subjective score which was significantly different from that of other 4 groups (P < 0.05); Mono+ 55 keV images had the highest subjective score which was significantly different from that of other 4 groups (P < 0.05).

4. Discussion

With the wide application of dual-energy CT and continuous technological innovation, different post-treatments and analysis algorithms have been continuously developed. Virtual single energy spectrum is one of the important post-treatment applications of dual-energy CT. It is generated by virtually calculating the CT values of substances under each single energy through dual-energy CT scan [4]. At present, the new generation of dual-source dual-energy CT can calculate single-energy images of any energy level ranging from 40 keV to 190 keV. Because substances with high atomic number such as iodine contrast agent have strong ability to absorb low energy X-ray photons, tissues such as blood vessels and lesions enhanced by contrast agent have better contrast than those under ordinary single energy CT scanning in low energy single energy spectrum images, and can thus be used to optimize the display of lesions. However, the lower the energy is, the lower the penetration ability of X-ray photons and the higher the noise is, which causes lower signal-to-noise ratio of the images and even affects the diagnosis. Therefore, the traditional virtual single energy spectrum image post-treatment technology (Mono_E) has not overcome the noise of low energy single energy image, which affects its wider application. For example, LV et al. [5] argues that 70 keV single energy images are the best for small display of hepatocellular carcinoma, while lower single energy images affect diagnosis due to too high noise. In recent years, the report on small pancreatic cancer with equal enhancement has attracted the attention of clinicians [6], because when small pancreatic cancer with equal enhancement is enhanced, it is difficult to detect it. However, this type of pancreatic cancer is often early in the focus and the prognosis can be significantly improved after surgery [7]. This is precisely the short board of traditional single energy CT images.

Mono+, the new generation of virtual monoenergetic reconstructions of dual-source dual-energy CT, overcomes the shortcomings of traditional virtual monoenergetic reconstructions technology Mono E and highlights its advantages in noise reduction. In recent years, the clinical application of this new technique in abdomen has also been continuously reported [2] [8] [9]. It is believed that this technique can improve the image contrast, reduce noise, improve the image quality, and improve the detection rate of small pancreatic cancer. Thus, it is a very promising technique. Davide Bellini and other scholars found that Mono+ can overcome the significant noise of conventional mono images and thus improve the image quality when the energy value is lower than 70 keV through dual-source dual-energy CT examination of a group of pancreatic tumor patients. Objective image quality evaluation shows that the best contrast noise ratio can be obtained at Mono+ 40 keV energy level, while subjective image quality evaluation thinks that the best image quality can be obtained at Mono+ 55 keV energy level [10]. Similarly, Claudia Freillese and other scholars have also found that the best image quality can be achieved at Mono+ 55 keV energy level [2] in their research on the image quality of pancreatic cancer lesions and normal pancreatic tissues.

The purpose of this study is to explore the advantages of Mono+, the new generation of virtual monoenergetic reconstructions technology, in improving the imaging quality of portal vein system of pancreatic cancer patients. The comparison among Mono+ 70 keV, Mono_E 70 keV and 100 KV images (Figure 2) showed that there was no statistical difference in signal-to-noise ratio, but Mono+ 70 keV images still had lower noise; when keV value dropped to 55 keV, noise of Mono_E 50 keV images had increased significantly and the signal-to-noise ratio decreased significantly. Although this group of images improved the contrast between portal vein and pancreatic tissue, portal vein and tumor tissue, the noise was too high, which affected the image quality; noise of Mono+ 55 keV images was not significantly different from that of Mono+ 70 keV images and was slightly lower than that of 100 kV images. However the contrast between portal vein and pancreatic tissue, portal vein and tumor tissue in Mono+ 55 keV images was significantly increased, and CNRpv and CNR tumor were obviously improved. In this study, five groups of images were reconstructed by volume rendering technique (VRT) (Figure 3), minimum density projection technique (MIP) (Figure 4) and curved surface reconstruction technique (CPR) (Figure 5) respectively in a three-dimensional manner. Subjective

observation results showed that Mono+ 70 keV, Mono_E 70 keV and 100 KV images had little difference in image quality; Mono_E 55 keV images had the worst image quality due to the influence of noise. The edge of the image was rough, which was not conducive to showing the relationship between blood vessels and small tumors. However, Mono+ 55 keV images had better contrast and sharper edge of blood vessels; CPR images showed that the relationship between tumor and blood vessels and the boundary between tumor and pancreatic tissue were more clear.



Figure 2. The images of (a)-(e) Cross-sectional images of 100 keV, Mono_E 70 keV, Mono+ 70 keV, Mono_E 55 keV and Mono+ 55 keV showed that the signal-to-noise ratio of Mono+ 70 keV and Mono_E 55 keV were significantly higher than that of the 100-kv image. However, the Mono_E 70 keV image had no reducing noise effect compared with 100 kV image, and the Mono_E 55 keV image noise was significantly increased, and the signal-to-noise ratio was reduced, which affected the diagnosis.



Figure 3. The images of (a)-(e) were 100 keV, Mono_E 70 keV, Mono+ 70 keV, Mono_E 55 keV and Mono+ 55 keV VRT images respectively, showing that the portal vein system of Mono+ 55 keV was more clear and delicate, while the blood vessels of Mnon_E55 keV images were rough.



Figure 4. The images of (a)-(e) were respectively 100 keV, Mono_E 70 keV, Mono+ 70 keV, Mono_E 55 keV and Mono+ 55 keV MIP images, showing that the portal venous system of Mono+ 55 keV images had better contrast and were more clear and delicate than other images, while the Mnon_E55 keV images had large granules and rough blood vessels.



Figure 5. The images of (a)-(e) were respectively 100 keV, Mono_E 70 keV, Mono+ 70 keV, Mono_E 55 keV and Mono+ 55 keV CPR images, showing the relationship between portal vein and tumor. Mono+ 55 keV images showed stronger contrast between portal vein and tumor tissue and clearer edge relationship.

To sum up, Mono+ technology, the new generation of virtual monoenergetic reconstructions technology of dual source dual-energy CT, can significantly reduce image noise and improve image quality in pancreatic cancer portal vein system imaging. Choosing appropriate low keV virtual single energy image can obviously improve the contrast between tumor, blood vessel and pancreatic tissue. This can improve the detection rate of small pancreatic cancer and has important clinical significance for preoperative evaluation and treatment of pan-

creatic cancer.

Of course, this study also has some limitations, such as: too few cases may lack universality; at present, the new generation of dual-source dual-energy CT can calculate single-energy images of any energy level ranging from 40 keV to 190 keV. In this study, only the virtual monoenergetic reconstructions images of 55 keV and 70 keV were compared, but the images of other more energy levels were not studied. For the detection of small lesions of the pancreas, there may be more appropriate level virtual monoenergetic reconstructions image, which needs further study.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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