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Selection of kilovolt based on body mass index reduced radiation dose for computed tomography-guided radiofrequency ablation of liver tumors

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ABSTRACT

***Background*:** To explore the effect of kilovolt (kV) selection based on body mass index (BMI) on reducing the radiation dose of radiofrequency ablation (RFA) in liver tumours under computed tomography (CT) guidance. ***Materials and Methods*:** This study retrospectively reviewed CT-guided RFA of liver tumours performed between 1 January 2019 and 31 December 2019. The radiation dose received by the patients was recorded after the planning, execution and surgery. The RFA protocol for liver tumours was subsequently modified according to the patients' BMI. Changes in tube voltage and tube current were recorded for the RFA protocol based on BMI. The image quality and overall operator satisfaction were recorded for each case based on the BMI-modified protocol. The radiation dose received by the patients was also recorded, and the degree of dose reduction adjusted based on BMI was calculated. ***Results*:** The results showed that the mean (± SD) overall CT dose index (CTDI) of CT-guided RFA was 12.83 ± 3.78 mGy. Following protocol modification, the mean CTDI decreased to 3.84 ± 2.24 mGy, a 70.07% reduction overall. The image quality was slightly lower compared with before the modification, but the image quality in both stages met the needs of CT-guided RFA for liver tumours. Electrode needle display and operator confidence satisfaction showed no significant difference between the groups ($P > 0.05$). ***Conclusion*:** Modification of the BMI-based kV protocol could significantly reduce the radiation dose received by patients during CT-guided ablation of liver tumours. Furthermore, the image quality was not significantly compromised.

INTRODUCTION

Radiofrequency ablation (RFA) is widely used in the treatment of abdominal tumour patients due to its high tolerance, definite efficacy and limited side effects [1–3]. RFA is commonly used for the treatment of abdominal tumours, such as those arising from liver cancer [4], gastric cancer [5], colon cancer [6] and pancreatic cancer [7].

Image-guided ablative techniques help physicians anatomically locate the patient's tumour site because computed tomography (CT) images provide good spatial resolution, especially for patients with abdominal obesity [8, 9]. Despite those benefits, and considering the complexity of CT-guided procedures and the complex additional imaging needed to monitor the therapeutic procedures and their outcomes, the risks associated with this procedure's radiation dose are concerning, as the total radiation dose can reach high levels. Studies have shown that radiation exposure increases the risk of developing cancer or promoting cancer progression, and in some studies, different methods have been used to adjust CT scan protocols to reduce the radiation dose received by patients [10–12]. The use of different CT devices reduces the radiation dose received by the patient during RFA treatment [10]. It has been shown that the kilovolt (kV) value can be adjusted to reduce the radiation dose received by the patient during RFA treatment [11]. There are currently few studies on selecting kV based on body mass index (BMI) to reduce the radiation dose in patients undergoing RFA for liver tumours. In this study, the relationship between BMI and the radiation dose for the CT-guided ablation of liver tumours is investigated. Based on this, the BMI reduces the radiation dose received by patients without significantly sacrificing image quality.

MATERIALS AND METHODS

General information

This study was approved by the Ethics Committee of the First Hospital of Hebei Medical University (Approval No. 20190479). The patients signed an informed consent form and agreed to participate in this study.

The study was a two-stage (before and after) clinical trial. Initially, the routine use of CT was

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recommended in the assessment of the radiation dose. The CT protocol was then modified based on the patients' BMI. In the first stage, the patients' data were collected, and the radiation dose of the patients was recorded while performing RFA treatment. The radiation dose of the patients was automatically generated using CT, and the radiation dose of each treatment was calculated for a single scan. In the second stage, patients were divided into groups according to their BMI, and different kVs were scanned during RFA treatment according to the groups.

CT protocol for the first-stage patients

This research was a retrospective study using data on patients who underwent CT-guided RFA of liver tumours.

The inclusion criteria were as follows: (1) the number of liver tumours per patient was one to three, with the diameter of a single lesion being <5 cm and the maximum diameter of multiple lesions being <3 cm; (2) no intractable massive ascites; (3) the indications conform to CT-guided RFA of hepatic tumours; (4) the consent of the patient and their family was received; and (5) the patients' data were kept intact.

The exclusion criteria were as follows: (1) unconscious patients; (2) patients with irreversible coagulopathy; (3) patients with diffuse liver metastasis; (4) patients with a systemic infection; (5) patients with end-stage organ failure; and (6) there were other organs with malignant tumour metastasis in addition to the liver.

Basic patient information (including operative date, age, gender, height and weight) and treatment details (the tumour size and therapy times) were recorded. Computed tomography scan parameters of the procedure (tube voltage, tube current, CT dose index (CTDI) and dose length product (DLP)) were recorded to calculate the radiation dose.

In the first stage, 100 patients (aged 29–90 years: 55 men and 45 women) underwent conventional CT-guided RFA of liver tumours. The average patient BMI was 24.41 ± 3.86 kg/m^2.

The protocol modification in the second stage

The scan protocol was modified based on the patients' BMI: 70 kV for BMI≤24 kg/m^2, 80 kV for BMI>24 kg/m^2 but<28 kg/m^2 and 100 kV for BMI≥28 kg/m^2. This protocol was subsequently applied to patients undergoing CT-guided RFA of liver tumours between 1 February 2020 and 31 March 2021 [13].

Basic patient information (operative date, age, gender, height and weight) and treatment details (the tumour size and therapy times) were recorded.

CT-guided percutaneous procedures

A 64-MDCT scanner (INCISIVE, Philips) was used for all CT-guided RFA of hepatic tumours: the rotation time was 0.5 seconds, and the detector width was 64 × 0.625 mm.

The scan protocol was performed with 120 kV and automatic milliampere seconds in the first-stage patients (dose report index [DRI] was 23). In the modification phase, the milliampere second-adaption algorithm with 70 kV, 80 kV and 100 kV was performed according to the patient's BMI, and the DRI was equal to 23.

Radiofrequency ablation

All CT-guided RFAs were performed using RATA RFAs, and radiofrequency needles were performed using RATA multistage electrode needles.

Multiple overlapping RFAs were performed for each tumour, the target temperature was set at 85□ and the time limit for each ablation was five minutes after reaching the target temperature.

Dose calculation of CT-guided radiofrequency ablations

Computed tomography-guided RFA was adopted in three steps to effectively destroy solid tumours in the liver.

Step 1: Planning, including axial imaging of targeted lesions, evaluation of the trajectory of percutaneous to lesions and evaluation of the number of overlapping ablations required to achieve complete ablation.

Step 2: Evaluation of the accuracy of electrode placements and repositioning involving multiple iterations.

Step 3: Postoperative evaluation after electrode removal was performed to assess immediate complications and treatment success. The CTDI volume (CTDIvol) and DLP were recorded.

Image analysis

Image quality assessment was performed by two senior radiologists using the PACS diagnostic workstation. The images were displayed in the liver window setting (WL: 60 HU, WW: 180 HU), and the window width and window level were adjusted according to the nature of the lesion for evaluation.

Two senior radiologists evaluated the image quality of randomised CT images before and after protocol modification over a three-week period. Both radiologists assessed the image quality according to the description in the European standard guidelines for the quality of abdominal CT examinations [14] (5 points: excellent image quality to differentiate lesions; 4 points: the image quality of slightly blurred lesions is not restricted; 3 points: the image quality of moderately blurred lesions is mildly restricted; 2 points: the image quality of severely vague or poorly defined lesions is restricted; and 1 point: severe degradation of the image quality makes reliable interpretation impossible).

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Operator confidence satisfaction was also assessed as follows: 5 points: complete confidence in diagnostic interpretation; 4 points: with a certain degree of confidence in diagnostic interpretation; 3 points: confidence visualising anomalies under limited conditions; 2 points: there are some unacceptable diagnostic images; and 1 point: totally unacceptable diagnostic image).

1.6 Statistical analysis

The SPSS20.0 statistical software was used for statistical data analysis. Qualitative data were tested for normality and homogeneity of variance, with $P < 0.05$ indicating a statistically significant difference.

RESULTS

Basic data

Table 1 shows the basic information of patients. There was no significant difference ($P > 0.05$) in age and BMI between the two stages, which can be used for a comparative study (table 1).

Table 1. Comparison of age and BMI of patients in two stages.

	age(y)	BMI (kg/m^2)
Stage 1	60.52±17.21	24.41±3.86
Stage 2	61.24±18.87	24.68±3.97
***t* value**	-0.522	-0.443
***p* value**	0.604	0.659

Note: BMI: Body mass index. Stage 1: The primary stage. Stage 2: The protocol modification stage.

Image quality

Figure 1 shows the CT images of the liver under different conditions. The image quality of stage 1 was higher than that of stage 2, and the difference was statistically significant ($P < 0.05$), but the image quality of both stages was greater than 3.8 points, which met the needs of CT-guided RFA for liver tumours (table 2).

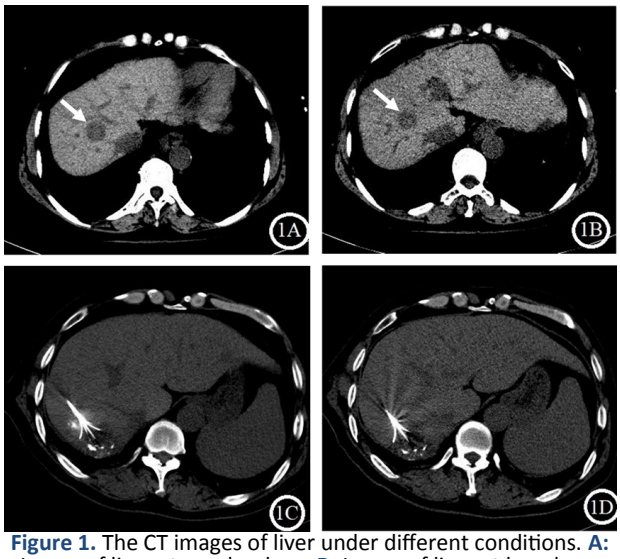

Figure 1. The CT images of liver under different conditions. **A:** Image of liver at regular dose; **B:** Image of liver at low dose; hepatic mass was arrowed. **C:** The needle electrode is shown in a liver mass at conventional dose; **D:** The needle electrode at low dose.

Table 2. Image quality, needle electrode display and operator confidence satisfaction in two-stage.

	IQ (points)	NED (points)	OCS (point)
Stage1	4.16±0.22	4.31±0.34	4.29±0.31
Stage2	3.89±0.24	4.23±0.36	4.25±0.38
***t* value**	5.146	0.770	-0.390
***p* value**	0.000	0.447	0.701

Note: IQ: image quality, NED: Needle electrode display, OCS: Operator confidence satisfaction. Stage 1: The primary stage. Stage 2: The protocol modification stage.

There was no statistically significant difference between the needle electrode in the two stages and between the operators' confidence satisfaction. The results are shown in table 2 and figure 1.

Table 3. Radiation dose comparison between two stages.

	$CTDI_{VOL}$(mGY)	single DLP(mGY.cm)
Stage 1	12.83±3.78	344.91±106.85
Stage 2	3.84±2.24	103.19±62.81
***t* value**	-21.34	-20.63
***p* value**	0.000	0.000

Note: CTDI: CT dose index, DLP: Dose Length Product. Stage 1: The primary stage. Stage 2: The protocol modification stage.

The radiation dose

The CTDIvol of CT-guided RFA in stage 1 was 12.83 ± 3.78 mGy. The single DLP of CT-guided RFA in stage 1 was 344.91 ± 106.85 mGy cm. After the modification of the CT protocol, the average CTDIvol in stage 2 decreased to 3.84 ± 2.24 mGy, an overall decrease of 70.07% ($P < 0.05$) (table 3). The single DLP of CT-guided RFA in stage 2 was 103.19 ± 62.81 mGy cm.

DISCUSSION

In view of the increasing use of CT in diagnosis and monitoring, there is a growing concern about the radiation doses received by patients [15,16].

The mean CTDIvol for abdominal imaging in adults is 25mGy [17]. However, the corresponding statistical data and reference range of CT-guided surgery have not been established. Sarti *et al.* [18] showed that the radiation dose received by patients can be reduced without prolonging the operation time and still meeting the image requirements using a low-dose CT scanning technique. Cao *et al.* [19] have shown that in diagnostic CT examination, the radiation dose may be reduced without loss of diagnostic image quality. Intervention doctors who perform CT-guided procedures should consider low-dose CT scanning protocols. As described in this study, the radiation dose received by the patient should be kept as low as possible when successful completion of RFA is reasonably achieved. When feasible, non-ionic radiation guidance, such as ultrasound and nuclear magnetic resonance, should be preferred to reduce the radiation dose of patients.

Low-dose scanning techniques have been successfully used for CT-guided chest biopsies [20,21]. Liu *et al.* [20] showed that the dose was reduced by

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47% using an ultra-low dose CT scanning protocol without reducing the success rate of biopsy or patient safety. A study by Huo *et al.* [21] showed that changing the CT scan protocol significantly reduced the radiation dose received by the patient by more than 82%.

Fang *et al.* [22] found that scanning with fixed milliampere (50 mA) can reduce the CT dose by 47.9% in CT-guided microwave ablation for liver cancer. The results of this study showed that the mean dose reduction rate of CT-guided liver tumour ablation was 70.07%, which was higher than that found by Fang *et al.* [22]. Due to the use of automatic milliampere scanning, which adjusts the kV according to the patient's BMI, CT image quality is better guaranteed, and the image quality of low-dose scanning is close to four points. The needle electrode display and operator confidence satisfaction were not statistically significant before and after the modification of the CT scanning protocol. The low-dose scanning protocol used in this study reduced the radiation dose for patients but had no effect on the operation of CT-guided RFA for liver tumours. Studies have shown that adjusting the CT scan schedule according to the patient's body weight is a feasible way to reduce the radiation dose of CT [23,24]. Zhu *et al.* [23] showed that reducing the radiation dose to coronary CT angiography (CTA) in patients with high heart rates based on BMI. In previous studies, low kVs were applied to various CTA imaging techniques, which can personalise the reduction of the patient radiation dose while ensuring image quality [23, 24].

In this study, it was found that adjusting the kV according to the patients' BMI was more conducive to reducing their radiation dose without reducing the image quality. With the decrease in the kV value, the contrast of the image was enhanced, which was more conducive to the display of the electrode needle. However, this study still has some limitations. First, the number of samples included in this study was 100, which was relatively small. More case samples should be collected for subsequent studies to further verify the conclusions of this paper. Second, there were only three CT scanning schemes based on BMI in this study. The CT scanning scheme should be adjusted according to the BMI to find the best scheme based on the BMI of patients and further reduce the radiation brought about by CT scanning.

CONCLUSION

The modification of the CT scan protocol based on patients' BMI significantly reduced the radiation dose for CT-guided percutaneous ablation of liver tumours without significantly reducing the image quality and operator confidence satisfaction.

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Not applicable.

***Ethics approval and consent to participate*:** This study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of the First Hospital of Hebei Medical University. Written informed consent was obtained from all participants in this study.

***Availability of data and materials*:** All data generated or analyzed during this study are included in this published article.

***Competing interests*:** All of the authors had no any personal, financial, commercial, or academic conflicts of interest separately.

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