Original Article

Relationship of body mass index and abdominal fat with radiation dose received during preoperative liver CT in potential living liver donors: a cross-sectional study

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Background: Although contrast-enhanced computed tomography (CT) is currently the most widely-used imaging modality for the preoperative evaluation of potential living liver donors, radiation exposure remains a major concern. The present study aimed to determine the relationship of body mass index (BMI) and abdominal fat with the effective radiation dose received during liver CT scans as part of a pre-donation work-up in potential living donors.

Methods: This retrospective cross-sectional study included 695 potential living donors (mean age, 30.5±9.7 years; 445 men and 250 women) who had undergone preoperative liver CT scans between 2017 and 2018. The following measures were evaluated: BMI, abdominal fat as measured at the level of the third lumbar vertebra, and effective dose based on the dose length product (DLP). Correlations between the effective dose and other variables were evaluated using Pearson's correlation coefficient.

Results: The mean BMI, total fat area (TFA), and effective dose were 23.6±3.3 kg/m^2, 218.7±110.0 cm^2, and 9.4±3.3 mSv, respectively. The effective dose during liver CT scans had a strong positive correlation with both BMI (r=0.715; P<0.001) and TFA (r=0.792; P<0.001). As BMI and TFA increased, so did the effective dose.

Conclusions: Higher BMI and TFA significantly increased the radiation dose received during liver CT scans in potential living donors.

Keywords: Computed tomography (CT); liver transplantation (LT); living donors; radiation dose

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Introduction

Liver transplantation (LT) is the most effective treatment for end-stage liver disease (1), and living donor LT (LDLT) is frequently performed, due to a shortage of deceased organ donors (2). The main clinical concern with LDLT is the risk to living donors who are generally healthy prior to the LT (1). To reduce the risks of LDLT and ensure donor safety, careful preoperative evaluation of hepatic parenchyma, anatomical variations in the hepatic vasculature, and precise estimation of hepatic volume are crucial for appropriate donor selection and surgical planning (3,4). Contrast-enhanced computed tomography (CT) is currently the most widely-used imaging modality for preoperative evaluation in LDLT because of its superior spatial resolution, easy accessibility, and short acquisition time (3,5,6). However, radiation exposure is a major concern with CT, especially for younger living donors, as cumulative radiation doses throughout a person's lifetime may increase their potential risk of cancer development (7).

Various strategies have been proposed to reduce the radiation dose to patients, in accordance with the principle of ALARA, which means to keep the radiation dose "as low as reasonably achievable". Some of these strategies include the following: tube current modulation, lower tube voltage protocols, automatic exposure control (AEC), and iterative reconstruction (8-11). Of these strategies, AEC, which aims to automatically adjusts the tube current to the patient size, is widely used with multidetector CT systems, providing a substantial reduction in radiation dose while maintaining adequate image quality (9,12). Meanwhile, it is already well-known that patients with a larger body habitus receive a significantly higher radiation dose during abdominopelvic CT scans when an AEC system is used (13). Previous studies have investigated the effects of patients' body weight, cross-sectional area, and anteroposterior diameter on doses of ionizing radiation during abdominopelvic CT scans using AEC (14-17). However, limited studies have evaluated the relationship between the abdominal fat and radiation dose during abdominopelvic CT scans (13,18). To the best of our knowledge, no previous studies have evaluated the relationship of body mass index (BMI) and abdominal fat with the radiation dose during liver CT scans, particularly when focused on potential living donors, who are young and healthy.

Therefore, the purpose of the present study was to determine the relationship of BMI and abdominal fat with the effective dose received during liver CT scans as part of a pre-donation work-up in potential living liver donors. We present the following article in accordance with the STROBE reporting checklist (available at https://qims.amegroups.com/article/view/10.21037/qims-21-977/rc).

Methods

The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The present study was approved by the Institutional Review Board of Asan Medical Center. The requirement for written informed consent was waived due to the retrospective nature of the study.

Study population

We retrospectively searched the database from Asan Medical Center to identify living liver donor candidates who had undergone preoperative CT imaging of the liver between January 2017 and December 2018. The potential donors underwent CT imaging of the liver as part of a pre-donation work-up in order to evaluate for hepatic parenchyma and anatomical variations in the hepatic vasculature, and to estimate the liver volume. Subjects who had fully visible abdominal fat at the third lumbar vertebra level on CT imaging were included in this study. Donor candidates who had undergone CT imaging of the liver at outside hospital were excluded due to inconsistency in CT scan parameters.

CT acquisition

Preoperative CT imaging was performed using 64- or 128-multidetector scanners (Somatom series, Siemens, Erlangen, Germany). Unenhanced CT scans were obtained for the quantitative assessment of hepatic steatosis, followed by biphasic (hepatic arterial and portal venous phases) contrast-enhanced CT scans for the anatomical mapping of the hepatic vasculature and CT volumetry. The scan parameters are listed in *Table 1*. The tube current was controlled using the CARE Dose 4D software package (Siemens), an AEC system which modulates the tube current within different anatomic regions (z-axis) as well as within the section (angular). Based on a single anteroposterior or lateral topogram, CARE Dose 4D determined the adequate tube current level (mAs) for each section of the subject and modulated the tube current to maintain similar image quality throughout the scan length. Thus, the scan

Table 1 Computed tomography scan parameters

Parameters	Protocols
kV/effective mAs/rotation time, s	100/200/0.5
Detector collimation, mm	0.6
Pitch	1
Scan direction	Craniocaudal
Scan range	Non-contrast and hepatic arterial phase—from diaphragm to liver lower margin
	Portal venous phase—from diaphragm to symphysis pubis
Intravenous contrast	150 mL of iopromide (Ultravist 370, Bayer Schering Pharma, Berlin, Germany)

Table 2 Characteristics of the study population

Variables	n=695
Age, years	30.5±9.7
Sex, men:women	445:250
Body mass index, kg/m^2	23.6±3.3
Visceral fat area, cm^2	66.2±45.8
Subcutaneous fat area, cm^2	152.5±80.6
Total fat area, cm^2	218.7±110.0
Dose length product, mGy·cm	623.4±218.0
Effective dose, mSv	9.4±3.3

length and dose were specific to each subject. The software package then generated the dose length product (DLP) (mGy.cm) and total mAs for each examination, which was also specific to each subject. The effective dose (mSv) was calculated by multiplying the DLP with a conversion factor (k), which was defined as the region-specific normalized effective dose (19).

Body composition parameters

A single axial CT image at the level of the inferior endplate of the third lumbar vertebra was selected from each subject for processing. Abdominal CT image analyses were performed with a fully convolutional, network-based, automatic segmentation technique using a deep-learning system (20), and body composition was assessed using an artificial intelligence software (AID-UTM, iAID Inc., Seoul, Republic of Korea) (20). CT images were automatically segmented to generate boundaries and measure the abdominal fat. The visceral fat area (VFA, cm^2) and subcutaneous fat area (SFA, cm^2) were demarcated using fat tissue thresholds (−190 to −30 Hounsfield units). The total fat area (TFA, cm^2) was calculated by adding VFA and SFA.

Data collection

Data on age, sex, and anthropometric measurements (body weight and height) were collected for each subject. BMI was calculated as the body weight (kg) divided by the square of the height (m^2). The BMI status of subjects was determined using ethnicity-specific cutoff values, as follows: BMI <23 kg/m^2 for lean, 23–24.9 kg/m^2 for overweight, and ≥25 kg/m^2 for obese.

Statistical analyses

Descriptive data were expressed as mean ± standard deviation. The Shapiro-Wilk test was performed to check normality of distribution. Correlations between the effective dose and other variables were evaluated using Pearson's correlation coefficient. Statistical significance was set at P<0.05, and statistical analyses were performed using SPSS (version 23.0; IBM, Armonk, NY, USA).

Results

Characteristics of the study population

A total of 695 potential living liver donors (mean age, 30.5±9.7 years; 445 men and 250 women) were included for analysis. The characteristics of the study population are summarized in *Table 2*. The mean BMI was 23.6±3.3 kg/m^2, and in terms of abdominal fat parameters, the mean VFA, SFA, and TFA were 66.2±45.8, 152.5±80.6, and 218.7±110.0 cm^2, respectively. The mean DLP was

Table 3 Body mass index and abdominal fat according to quartile of effective dose and their correlations with effective dose

Quartile (Effective dose, mSv)	I (<7.15)	II (7.15–8.75)	III (8.75–10.82)	IV (>10.82)	Correlation coefficient (r) with effective dose	P value
Body mass index, kg/m^2	21.0±2.1	22.8±2.1	23.8±2.5	26.6±3.7	0.715	<0.001
Visceral fat area, cm^2	36.3±25.2	55.3±36.4	70.5±44.3	102.5±46.4	0.545	<0.001
Subcutaneous fat area, cm^2	88.1±45.0	129.5±46.9	159.9±54.6	232.2±88.2	0.770	<0.001
Total fat area, cm^2	124.4±60.7	184.7±65.6	230.4±75.3	334.7±105.8	0.792	<0.001

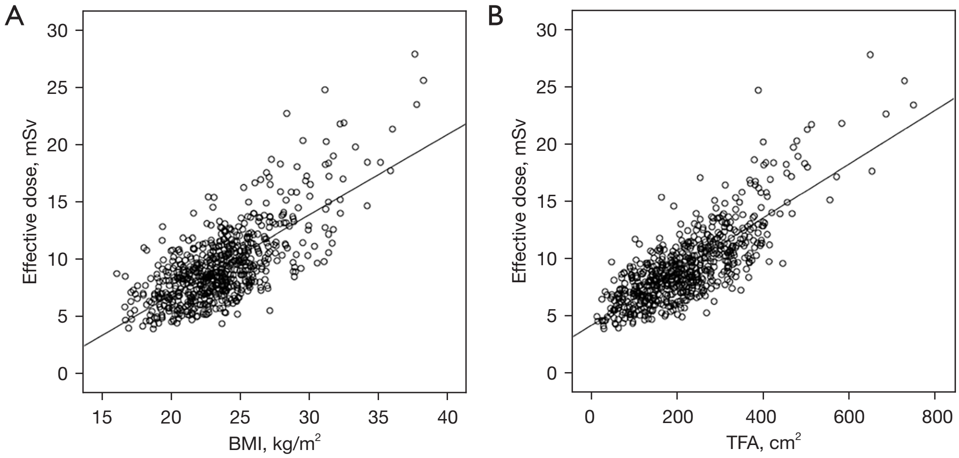

Figure 1 Scatter plot with linear regression line outlining the distribution of (A) BMI (kg/m^2) and effective dose (mSv); and (B) TFA (cm^2) and effective dose (mSv). BMI, body mass index; TFA, total fat area.

623.4±218.0 mGy·cm, and the mean effective dose was 9.4±3.3 mSv.

Correlation between effective dose and other variables

The effective dose had a strong positive correlation with BMI (r=0.715; P<0.001), SFA (r=0.770; P<0.001), and TFA (r=0.792; P<0.001), and a moderate positive correlation with VFA (r=0.545; P<0.001) (*Table 3*).

Relationship of BMI and abdominal fat on the effective dose

The mean effective dose for a BMI considered to be lean was 7.7±1.9 mSv, 9.2±2.0 mSv for overweight, and 12.3±3.9 mSv for obese, with statistically significant differences (P<0.001). The mean effective dose for a TFA <200 cm^2 was 7.5±1.8 mSv, for a TFA 200–400 cm^2 was 10.3±2.5 mSv, and for a TFA >400 cm^2 was 17.3±4.2 mSv, with statistically significant differences (P<0.001). As BMI and TFA increased, so did the effective dose (*Figure 1*).

Discussion

In the present study, the effective dose was found to be positively correlated with BMI and the area of abdominal fat. An increased BMI was associated with an increased effective dose from the multidetector CT, performed with an AEC system. An increase in abdominal fat significantly increased the effective dose from the liver CT performed as part of the pre-donation work-up for potential living donors.

To improve the success and reduce the risks of LDLT, the following are needed for appropriate donor selection and surgical planning: careful preoperative assessments of hepatic parenchyma, hepatic vascular anatomy, and liver volume estimation (3,4). Currently, contrast-enhanced multidetector CT is the most widely-used imaging modality for the preoperative evaluation of potential living liver donors, due to its excellent spatial resolution, easy accessibility, and short acquisition time (3,5,6). However, considerable disadvantage of CT imaging is radiation exposure (7). In terms of medical exposure, an effective dose >10 mSv is considered to be a moderate risk for a single exposure (21). In the present study, more than two-thirds of obese subjects (BMI >25 kg/m^2) had an effective dose >10 mSv. Considering that the living liver donor population is younger, and that a patient's cumulative radiation doses over their lifetime can increase the probability of developing cancer (7), alternative imaging modalities such as magnetic resonance imaging (MRI) should be considered, especially for potential living liver donors with a higher BMI. With recent technical advances such as increased gradient strength, refined pulse sequences, and novel contrast agents, MRI has the potential to serve as an "all-in-one" imaging modality, particularly regarding the degree of hepatic steatosis and detailed evaluation of vascular and biliary anatomy in potential living liver donors (22),

In a study by McLaughlin *et al*. (13), the total abdominal adipose tissue was more predictive of DLP than BMI, which is consistent with the results of the present study. Our study also demonstrated that TFA was more strongly correlated with effective dose than BMI. These results suggest that the estimation of total abdominal adiposity, more than BMI, may guide to reduce the radiation dose and facilitate dose optimization protocols when using AEC. A possible process would be to acquire a representative single-slice abdominal CT section at the level of the third vertebra and obtain an automated quantification of TFA (13). We believe that TFA-based optimization protocols from single-slice CT sections may provide an individualized approach for a more aggressive dose reduction in young and healthy living liver donors.

The present study has several limitations. This was a single-center retrospective study; therefore, the results should be prospectively validated in a multicenter study. Additionally, the mean BMI of our study population was quite low because the study population was Asian. Therefore, further studies in a Western population with a substantial proportion of subjects with a higher BMI would be beneficial. In this study, DLP-based effective dose estimation was used. However, according to a recent publication (23), DLP-based effective dose estimates differ significantly from organ dose-based effective dose estimates and may not be accurate compared to organ dose-based effective dose estimates. Further studies using organ dose-based effective dose estimates may be needed. Lastly, thick layers of subcutaneous fat may shield internal organs and act to reduce effective dose partly mitigating the additional mAs required for imaging. Accordingly, the results reported might be overestimates of the true effect of obesity on radiation dose.

In conclusion, the effective dose had a significant positive correlation with both BMI and abdominal fat during preoperative CT; therefore, increased BMI and abdominal fat significantly increased the radiation dose received during liver CT in potential living liver donors.

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Footnote

Reporting Checklist: The authors have completed the STROBE reporting checklist. Available at https://qims.amegroups.com/article/view/10.21037/qims-21-977/rc

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://qims.amegroups.com/article/view/10.21037/qims-21-977/coif). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The present study was approved by the Institutional Review Board of Asan Medical Center. The requirement for written informed consent was waived due to the retrospective nature of the study.

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