

# Assessment of Radiation Dose Delivered and Volume Measurement By Low- and High-Dose Diagnostic Computed Tomography: Anthropomorphic Liver Phantom Study

## Abstract

**Aim:** Liver volume measurement is a mandatory test before measure liver surgeries and transplantation. We aimed a study on the difference in volume measurement and radiation dose to an anthropomorphic liver phantom using high-dose and low-dose diagnostic computed tomography (CT). **Materials and Methods:** Several measurements of the manual total volume measurement done on an anthropomorphic liver phantom mounted with thermoluminescent dosimeter. We exposed the phantom with diagnostic CT, low-dose CT, and a low-dose CT with copper filter. **Results:** Phantom underwent ten scanning for each exposure. There was no significant difference in the total volume measurement in comparison to the phantom volume. The volume of phantom measured by low-dose CT, low-dose CT with copper phantom, and high-dose CT were  $1869 \pm 18 \text{ cm}^3$ ,  $1852 \pm 24 \text{ cm}^3$ , and  $1908 \pm 12 \text{ cm}^3$ , ( $P = 0.3$ ), respectively. However, the radiation dose delivered was significantly different (1.54 mGy, 0.77 mGy, and 5.84 mGy [ $P = 0.001$ ], respectively). **Conclusion:** Total liver volume measurement provides essential clinical information in several clinical conditions. We recommended that the volume measured by a low-dose CT has an excellent correlation with the diagnostic quality CT and should be a routine in the routine clinical practice. CT volumetry achieves the same result while using very less radiation exposure. It may also be used with functional imaging to give complete information.

**Keywords:** Anthropomorphic liver phantom, computed tomography, thermoluminescent dosimeter

## Introduction

Various modalities are available to image liver such as ultrasound, computed tomography (CT), magnetic resonance imaging (MRI), and radionuclide scintigraphy. The first three imaging techniques predominant depend on morphological changes to detect pathology, whereas MRI may detect both morphological and physiological changes. Radionuclide scintigraphy determines the function of the liver. Since physiological changes usually precede morphological alternation, scintigraphy has excellent potential for the early diagnosis of disease before irreversible function changes take place.<sup>[1]</sup> However, it has a lower spatial resolution and demonstrates only functional liver volume.

Assessment of the liver volume is mandatory before significant liver resection and liver transplant donor workup. Evaluation of total and segmental liver

volumes is crucial because of assuring appropriate graft size. That is one of the significant predictors of a successful outcome for both donor and recipient. In patients with preexisting chronic liver disease, postoperative liver failure after major hepatic resection is a paramount concern. Postoperative residual liver volume (future liver remnant [FLR]) to the standardized liver volume (SLV) ratio is an indicator in predicting the likelihood of it. A study of 301 extended right hepatectomies demonstrated an inverse correlation amongst small (<20%), intermediate (20%–30%), large (>30%) FLR volumes, and increasing risk for postoperative deaths.<sup>[2]</sup> In patients with normal liver parenchyma, a %FLR >25%–30% of the preoperative liver volume is considered sufficient for safe resection.<sup>[3]</sup> However, in patients with a compromised liver (e.g., fibrosis, steatosis, or cholestasis), a %FLR of >40% is preferred.<sup>[4]</sup>

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An accurate and noninvasive liver volumetry is necessary, and CT is a useful imaging modality for this purpose. It has a high spatial resolution, contrast resolution, and is noninvasive.<sup>[5]</sup> MDCT-volumetry has a crucial role in decision-making, monitoring, and predicting liver hypertrophy preoperatively and postoperatively.<sup>[6]</sup> Multiphase contrast-enhanced CT scans have the advantage of high-resolution diagnostic images that enable accurate measurements of segmental liver volume using a portal and hepatic vein as a landmark for the segmental division.

However, CT scanning is associated with significant radiation exposure. It is essential to justify CT examinations beforehand to be compliant with the ALARA principle (as low as reasonably achievable). The radiologist should make efforts to reduce the radiation dose of multiphase CT examinations while maintaining diagnostic quality.<sup>[7,8]</sup>

The purpose of our study was to measure the volume of anthropomorphic liver phantom using a low-dose CT scan and to compare it with standard diagnostic CT. We will also measure the radiation dose delivered to the phantom during low dose and diagnostic CT.

## Materials and Methods

### Acquisition parameter

The study was conducted in the tertiary care teaching hospital. An anthropomorphic liver phantom used for measuring liver volumes [Figure 1]. Glycerin was filled in the liver phantom (used as a contrast). Qualified CT technologists conducted all the examinations on a GE 64 slice diagnostic CT machine (GE LightSpeed VCT) with Xeleris software (Xeleris 2.1517 GE healthcare). A standard adult abdominal imaging protocol used for all acquisitions with the patient lying supine on a CT table. Parameters applied to diagnostic CT were current 271 mA, voltage 140kV, and matrix size  $512 \times 512$ . Low-dose CT was performed on a GE Infinia Hawkeye-4 low dose four-slice CT scanner. The parameters used for low-dose

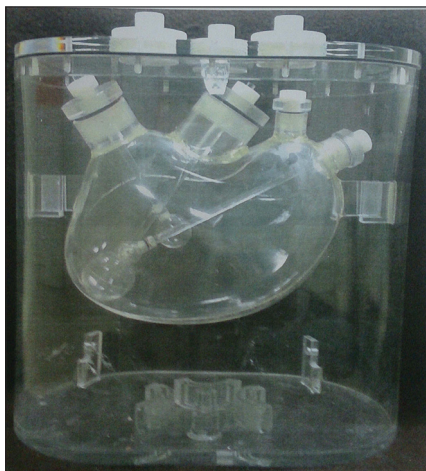


Figure 1: Anthropomorphic liver phantom used in the study

CT was current 2.5 mA, voltage 140 kV, and matrix size  $512 \times 512$ . Another low dose CT was done using the same imaging protocol with copper filter. A 3-mm thick copper plate is used as a copper filter. It is fixed over the X-ray tube of Infinia Hawkeye-4. It stops the radiation of lower 140 kV and further decreases the radiation dose to the liver phantom.<sup>[9]</sup> Dosage on the phantom calculated using the thermoluminescent dosimeter (TLD) during each acquisition. Ten measurements were done on anthropomorphic liver phantom by diagnostic CT, low-dose CT, and low-dose CT with copper filter.

### Calculation of volume of the liver phantom

The images of CT are processed in Xeleris workstation (Xeleris 2.1517 GE healthcare), GE healthcare, and transverse slices of phantom were saved and used for the calculation of volume. Liver volume was calculated using volume measurement software in the Xeleris software. A total of thirty transverse slices were obtained. We used a slice thickness of 0.625 mm and 5 mm for full diagnostic and low-dose CT, respectively. The polygonal region of interests was drawn manually over each axial image, and total volume measured.

### Calculation of dose estimation

For dose estimation, we used the lithium fluoride chip (LiF<sub>2</sub>) TLD [Figure 2]. We precisely placed the TLD chips in the same place during each image acquisition. After exposure, all TLD chips read on the TLD reader (Harshaw TLD™ Model 3500).

### Statistical analysis

The normality of the continuous variables assessed. A value of  $P < 0.05$  considered as statistically significant. The correlation coefficient  $R$  was calculated. Pearson coefficient  $R$  was used to quantify the association between the true and measured volumes.  $P < 0.05$  was considered statistically significant. All data analyses were performed on the Statistical package for the Social Sciences, version-23 (SPSS-23, IBM, Chicago, USA).

## Results

A total of ten separate acquisitions were done. The liver phantom volume measurements were done on low-dose CT,



Figure 2: Thermoluminescent dosimeter Chips (LiF)

low-dose CT with copper filter, and high-dose diagnostic CT [Figure 3]. The actual volume of the phantom was 1870 cm<sup>3</sup>. The volume of phantom measured by low-dose CT, low-dose CT with copper phantom, and high-dose CT were 1869 ± 18 cm<sup>3</sup>, 1852 ± 24 cm<sup>3</sup>, and 1908 ± 12 cm<sup>3</sup>, respectively. There was a significant positive correlation between phantom volume, the volume of phantom measured by low-dose CT ( $r = 0.95, P = 0.005$ ), and high-dose CT ( $r = 0.97, P = 0.003$ ). Although no significant difference was noted between the volume estimation by these techniques ( $P = 0.3$ ). The radiation dose delivered with low-dose CT and high-dose CT radiation dose was 1.54 mGy and 5.84 mGy [Table 1]. This difference was statistically very significant ( $P = 0.001$ ). The radiation dose further reduced significantly by using a copper filter, which was 0.77 mGy only ( $P = 0.002$ ).

### Discussion

Liver volume estimation in a prerequisite for the preoperative assessment of patients undergoing liver resection or liver transplantation. In the evaluation of suitability for the surgery, key considerations include preoperative baseline liver function, patient size, SLV, and postoperative residual liver volume (FLR).<sup>[10]</sup>

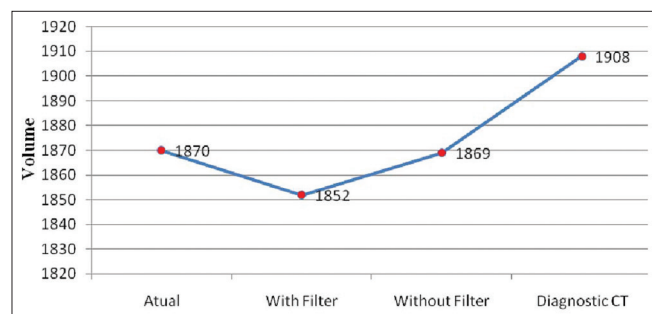


Figure 3: Volume estimated by low-dose computed tomography and diagnostic computed tomography

**Table 1: Dose estimation during diagnostic and low-dose computed tomography using thermoluminescent dosimeter badges**

Low-dose CT Dose estimated (mGy)		Diagnostic CT Dose estimated (mGy)
With copper filter	Without copper filter	
0.75	1.54	5.81
0.78	1.52	5.85
0.77	1.55	5.84
0.76	1.54	5.85
0.76	1.55	5.84
0.76	1.54	5.84
0.75	1.52	5.85
0.78	1.55	5.84
0.78	1.55	5.84
0.77	1.54	5.84
0.77	1.54	5.84

CT: Computed tomography

CT liver volumetry remains the most commonly used modality for measuring total and segmental liver volume. This modality is robust and very accurate. CT volumetry indirectly measures liver function and is used to exclude patients from planned liver resection. It also helps to select patients who will benefit from preoperative portal vein embolization. Future remnant liver volume measured by CT volumetry is used as an indirect measurement of the liver function and is currently the established method to determine whether a patient can safely undergo liver resection.<sup>[11,12]</sup>

The analysis of the liver volume from CT images performed using manual volumetry before the introduction of automated methods. It consists of manual tracing of the liver boundary on individual CT slices. The different slice volumes are summed to calculate an overall liver volume. It is accurate, but a time-consuming method and is patient dependent. It takes 20–30 min to assess a liver volume for one patient.<sup>[10]</sup> Various automated and semi-automated methods have been proposed to speed up the process and to avoid tedious operations.<sup>[5,13-15]</sup> Studies have shown that the semiautomatic segmentation algorithm substantially reduces the processing time while improving both accuracy and repeatability.<sup>[16]</sup> In our research, we spent near 15–20 to process every acquisition. However, we did not find a significant difference between the volume measured by the manual method and the actual phantom volume.

It is crucial to accurately measure liver volume, especially in patients with chronic liver disease or cirrhosis, where the size of the remnant liver becomes even more critical as a prognostic factor.<sup>[10]</sup> A graft-to-recipient weight ratio >0.8 or graft weight/standard liver volume ratio >40% for improving graft survival and for preventing postoperative graft dysfunction.<sup>[17,18]</sup> Researchers have also reported that a liver recipient with a graft-to-recipient weight ratio of <0.8 had a significantly lower chance of survival.<sup>[19]</sup>

In this regard, it is desirable to keep the degree of error due to the various factors to the minimal. As expected, that liver volumes calculated on 0.625-mm three-dimensional (3D) images would be more precise than those on thicker images due to a partial volume effect. In our study, we used thick slices to measure liver volume. This study demonstrated that calculated liver volume mildly increases by decreasing the slice thickness, probably due to the partial volume effects. However, it was not very significant. Some previous researches have demonstrated similar trends in CT and MRI-based organ volumetry. However, they did not include isotropic 3D image data.<sup>[20-22]</sup>

The most useful way to assess radiation dose to the organ doses is by direct measurement (on patients with TLD or phantom) or by indirect analysis through analysis of CT dose indexes and published conventional factors obtained from Monte Carlo simulation and mathematical phantoms.<sup>[23,24]</sup> We utilized the direct measurement method for this study.



As the CT scan uses ionizing radiation, the primary concern remains radiation exposure. We have shown that there is no significant difference between the volume estimation by three radiation techniques. However, the radiation burden by them was different significantly. This finding has a significant clinical implication that accurate liver volume measurement can be done with a low radiation burden.

It is a fact that the radiation doses from CT procedures are higher than from other ionizing imaging-based imaging modalities. One CT chest examination delivers about 400 times the dose delivered by a chest X-ray examination. CT represents only 5% of the total number of medical X-ray procedures worldwide; however, it contributes about 34% of the annual collective dose from all medical X-ray examinations to the population.<sup>[25]</sup> This study demonstrates the whole liver volume could be measured by the low-dose CT. We are, thus, avoiding unnecessary ionizing radiation.

In this study, we did not use SAIP (software-assisted image post-processing) tools. However, volumes measured by the manual method were not very different from the original sizes. It is in concordance with the previous study that automated whole-liver segmentation showed similar volume in comparison to manual approaches. However, it shows improved reproducibility and postprocessing duration.<sup>[26]</sup> Another limitation of this study was done on the phantom and did not include human participants with resected livers. We have measured only the whole liver volume as segmental anatomy could not be assessed on noncontrast low-dose CT. However, this could be very helpful when the entire volume of the liver is needed.

## Conclusion

In this study, we have demonstrated that there is no significant difference in total liver volume estimation with a low dose and high dose diagnostic CT study. However, the radiation burden by the diagnostic CT is very high in comparison to the low-dose CT. It could be further reduced by applying a copper filter. We recommended that to implement ALARA practice and diagnostic reference levels, we may use a low dose of CT study. Morphological volumetric evaluation of the liver may be combined with the use of functional imaging to reflect the functional liver volume more accurately.

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## Conflicts of interest

There are no conflicts of interest.

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