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Two-dimensional ultrasound: can it replace computed tomography in liver volume assessment?

Shimaa Farghaly¹, Marwa Makhoul^{1*} and Mahmoud Refaat Shehata²

Abstract

Background: Liver volume estimation is considered as an integral part in preoperative evaluation in patients undergoing liver transplantation; computed tomography and magnetic resonance imaging are considered the gold standard methods for liver volume estimation, and both are reliable and valid in determination of liver volume via manual and semi-automated methods. Reliable and accurate set of three simple measurement planes using two-dimensional ultrasound for volumetric assessment of liver was determined, and predictive equation using these three simple measurements was performed, which is simple to perform and easy to calculate, in order to evaluate liver volume and validate these measurements against CT images. Our aim in this study was to evaluate the efficacy and validity of two-dimensional ultrasound in liver volume estimation compared to CT volumetry as a gold standard.

Results: A strong linear positive correlation with no statistical significant difference was found between 2D US and semi-automated CT volumetric, and result was $r = 0.7402$ and $p > 0.05$, with an average liver volume of $1572.10 (\pm 326.43) \text{ cm}^3$ and $1559.30 (\pm 381.02) \text{ cm}^3$ respectively.

No statistically significant difference was found also between the two modalities in different age groups and different sexes.

Conclusion: Simple linear two-dimensional ultrasound could be considered an efficient, accurate, and trustable tool for liver volume measurement in clinical practice.

Keywords: Liver, Volumetry, Two-dimensional ultrasound, Semi-automated technique, Multi-slice computed tomography

Background

Liver volume estimation is considered as an integral part in preoperative evaluation in patients undergoing liver transplantation and determines the surgical respectability of hepatic focal lesions by assessment of remnant liver volume [1].

Computed tomography (CT) is a very good tool for volume assessment as it is noninvasive with high contrast and spatial resolution [2]. Manual tracing of the liver boundaries on individual CT images is the standard technique for liver volume calculation, and this yields accurate but subjective results; however, this technique

is time-consuming as it takes 25–40 min on average for liver volume assessment in one patient [3]. Automated computerized liver volumetry developed with advanced technology replaced manual liver volumetry [4]. Luciani et al. [5] reported that manual and automated CT liver volumetry were strongly correlated, but automated method was significantly time saving than the manual method.

Semi-automated segmentation techniques using mathematical models based on histogram cluster analysis were introduced [6], with time saving and improvement in accuracy and repeatability [7]. Although computed tomography (CT) and magnetic resonance imaging (MRI) are considered the gold standard methods for liver volume estimation, and both are reliable and valid in determination of liver volume via manual and semi-

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automated methods [8], CT has risk of ionizing radiation, and MRI causes issues of claustrophobia and it is contraindicated in the case of pacemaker and cochlear implants [9]. So, there is still a need for a simple, reliable, uncomplicated, and valid technique that can be trusted for liver volume assessment [10].

Ultrasound evaluation of liver size is available, inexpensive, and comparably a fast imaging technique which does not use ionizing radiation, and single, simple linear ultrasound measurements of the liver are easily performed, but they are limited, as they provide dimensional information at only one site within one lobe of the liver (right lobe) [11].

Many attempts to predict liver volume from simple linear ultrasound measurements was performed. Studies of Elstein et al., Glenn et al., and Zoli et al. [11] have previously developed equations to determine liver volume, but their accuracy was not reported. Kitajima et al. [12] reported the possibility of performing liver volumetry by means of conventional ultrasound in good correlation with actual specimen volume. Also, Xu et al. [13] reported the usefulness of three-dimensional ultrasound (3D US) volumetric evaluation in correlation with true volume; however, it is not universally proven to be successful for 3D evaluation of the liver because of its limitations, both physically and those related to variable reproducibility of the exam.

Childs et al. [10] determined reliable and accurate set of three simple measurements planes using two-dimensional (2D) ultrasound for volumetric assessment of liver. Then, Childs et al. [14] performed predictive equation using these three simple measurements, which is simple to perform and easy to calculate, in order to evaluate liver volume and validate these measurements against CT images.

The aim of this study is to evaluate the efficacy and validity of 2D ultrasound in liver volume estimation using Childs et al.'s equation compared to CT volumetry as a gold standard.

Methods

2D ultrasound volumetric assessment of the liver was performed in 100 patients who underwent tri-phasic multi-slice computed tomography (MSCT) abdomen for reasons other than related to liver such as acute abdomen, renal mass assessment, adnexal, and pelvic lesions which were enrolled in this prospective study from October 2017 to March 2018. Patients under 18 years old or with abnormal liver function tests were excluded.

The study was carried out after obtaining the permission of the Ethics Committee of Scientific Research, with informed consent from the patients.

All CT examination was performed using 16-MSCT scanner (Light speed, GE Healthcare, USA) with tube

voltage of 120 KV, tube current of 150–280 mA, and a 512×512 -pixel matrix. Then, data were reconstructed into 0.625-mm-slice images.

Non-contrast standard acquisition of abdomen was done first, followed by triphasic examination by administration of 100 ml of non-ionic contrast agent Ultravist 370 mg iodine concentration (Iopromide 0.769 g) in arterial, portal, and delayed phases. Then, volumetric assessment of the liver was done using semi-automated segmentation technique on Advantage Adw 4.6 GE work station.

Data analysis

CT liver volumes were calculated by two radiologists conjoint with more than 10 years' experience in CT using liver analysis application software, which used the density differences in portal/venous scan images to obtain semi-automated liver segmentation. The gall bladder and the main vessels, such as the retro-hepatic inferior vena cava vein, were manually excluded from segmentation volume. A volumetric reconstruction of the liver and quantification of total liver volume (TLV) were obtained.

The semi-automated volumetric measurement was divided into three steps (Fig. 1). *The first step* was manual delineation, which worked on two-dimensional (2D) view. It captured the cross section of the liver by user input control points. *The second step* was 3D surface reconstruction which worked with radial basis function based on the manual delineation. *The last step* was surface evolution, which evolved the reconstructed 3D surface using a level-set framework comprising both image and shape information.

Ultrasound volumetry

Two radiologists with more than 10 years' experience in US performed U/S examination conjointly using Philips ultrasound system (Affiniti 50G, Germany) with convex probe C6-2.

Two images of the liver were taken according to Childs et al.

- The first image (termed image 1) was taken with the transducer placed longitudinally in the midline parallel to the xiphisternum for left hepatic lobe delineation.
- The second image (termed image 2) was taken with the transducer orientated longitudinally in the mid-clavicular line for right hepatic lobe delineation.

One measurement was taken from image 1, a linear measurement of the maximum anterior to posterior diameter of the liver (measurement A), as shown in Fig. 2a, and two measurements were taken from image 2, a linear

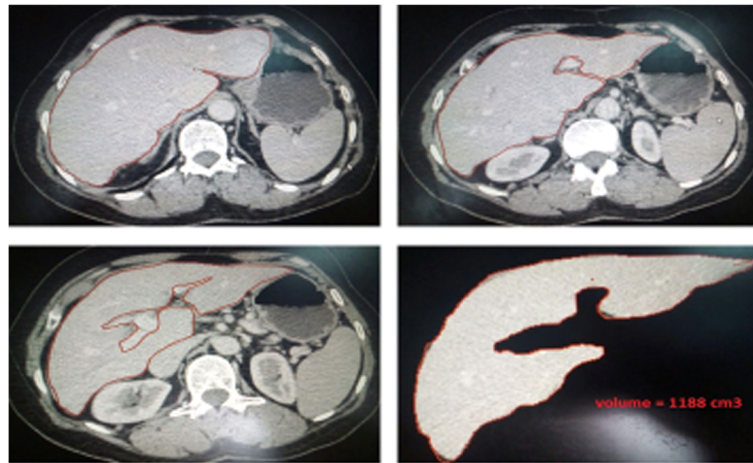


Fig. 1 Example of semi-automated CT volumetry steps

measurement from the dome to the tip of the right lobe of the liver (measurement B) as shown in Fig. 2b and a linear measurement of the maximum anterior to posterior diameter of the liver in this image (measurement C) as shown in Fig. 2c.

The three measurements were then used to determine liver volume according to Childs et al.'s equation [14] as liver volume (cm^3) = $343.71 + (0.84 \times \text{ABC})$ where ABC is the product of the three linear measurements.

Data were statistically described in terms of range, mean, standard deviation, frequencies (number of cases), and percentages when appropriate.

Difference between variables was done using Mann-Whitney test. Statistical significance was set at $p < 0.05$, and all reported p values were two sided. Correlation coefficient (r) between two variables was set as value of r which is always between +1 and -1.

Results

One hundred patients were included in this study, 50 males and 50 females, with age ranged from 28–77 years, and the mean age was 50.58 years.

The liver volume was estimated for each case by both U/S and semi-automated MSCT. The average liver volume by U/S was $1572.10 \pm 326.43 \text{ cm}^3$, while the average liver volume by semi-automated CT was $1559.30 \pm 381.02 \text{ cm}^3$ (Table 1, Fig. 3), with no statistical significant difference found between both of them as the p value was 0.798 (> 0.05).

As regards age, average liver volume obtained by U/S in cases less than 50 years was $1524.80 \pm 316 \text{ cm}^3$ and in more than 50 years was $1612.40 \pm 332.38 \text{ cm}^3$, while the average liver volume by CT in cases less than 50 years was $1504.90 \pm 337.27 \text{ cm}^3$ and in more than 50 years was $1605 \pm 412.14 \text{ cm}^3$, with no statistical significant difference found in both methods as the p value was 0.182 and 0.19 respectively (> 0.05) (Table 2).

The average liver volume by U/S in male was $1606.10 \pm 398.04 \text{ cm}^3$, while in female was $1538.10 \pm 233.42 \text{ cm}^3$, and the average liver volume in male by semi-automated CT volumetry was $1566 \pm 418.22 \text{ cm}^3$, while in female was $1552.50 \pm 343.98 \text{ cm}^3$, with also no statistical significant difference found between them as regards sex as the p value was 0.3 and 0.86 respectively (> 0.05) (Table 3).

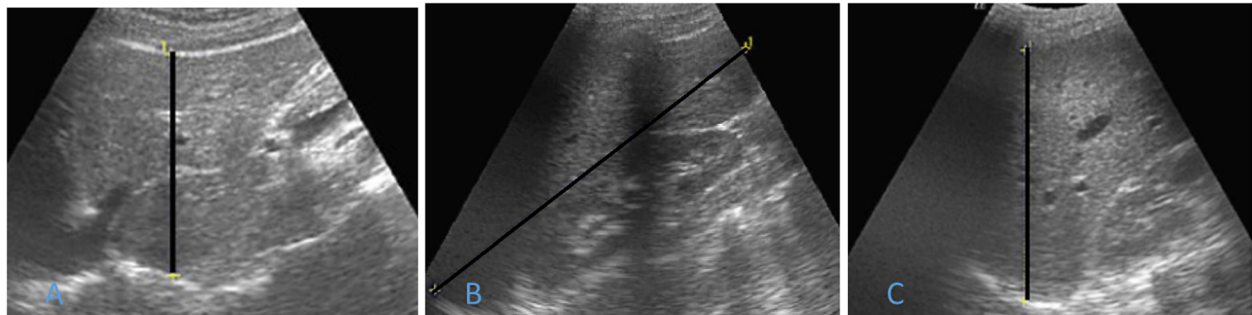


Fig. 2 The three linear measurements of liver. **a** The left lobe of the liver. **b, c** The right lobe of the liver

Table 1 Comparison of average liver volume by US and semi-automated CT volumetry

Method	Mean \pm SD (N = 100)	p value
US	1572.10 \pm 326.43	0.798
MSCT	1559.30 \pm 381.02	

In the evaluation of linear association with the Pearson product-moment correlation coefficient (r) (which measures the strength and direction of the linear relationship between two variables on a scatter plot) by comparing the results obtained by U/S volumetry with semi-automated MSCT volumetry as gold standard, we found that the value of r was 0.7402 which means strong linear positive correlation between them (Fig. 4).

Discussion

Liver size is a significant indicator for the presence of a disease process; also, it aids in treatment planning for liver transplantation and resection. In addition, it is used post-therapy for assessment of graft regeneration and treatment response evaluation in case of liver malignancy [1], and it is used after portal vein embolization for evaluation of the increase in future liver remnant volume [15, 16].

Liver volume is a better way for the assessment of liver size as it represents the entire liver rather than linear measurements in single planes [17]. Computed tomography (CT) has been widely used for volumetric assessment of the liver, magnetic resonance imaging (MRI)

Table 2 Average liver volume by US and CT as regards age

	Age		
	Less than 50 (N = 46)	50 or more (N = 54)	p value
US	1524.80 \pm 316.34	1612.40 \pm 332.38	0.182
MSCT	1504.90 \pm 337.27	1605.50 \pm 412.14	0.19

and ultrasound also, and has shown trustable organ volume measurements in light of appropriate scanning protocols [1].

Many previous studies have tried to evaluate and validate various imaging modalities for liver volumetry; however, there is no clear evidence about the most accurate method [5].

CT volumetry in combination with dedicated software plays important role in the evaluation of candidates for liver donor transplantation as it shows accurate estimation of graft dimension before transplant [18]. It has been performed by manual tracing of the liver boundary and summation of the liver area on each axial section, but this technique is operator dependent and time-consuming.

Although with advanced technology, automated and semi-automated volumetric measurements have been carried out to replace manual liver volumetry for accurate liver volume calculation [3]; however, there is still need for simple and uncomplicated technique that can be trusted for liver volume assessment [10].

Despite the widespread 3D ultrasound and its simplicity in the assessment of liver size, it is not proved to be

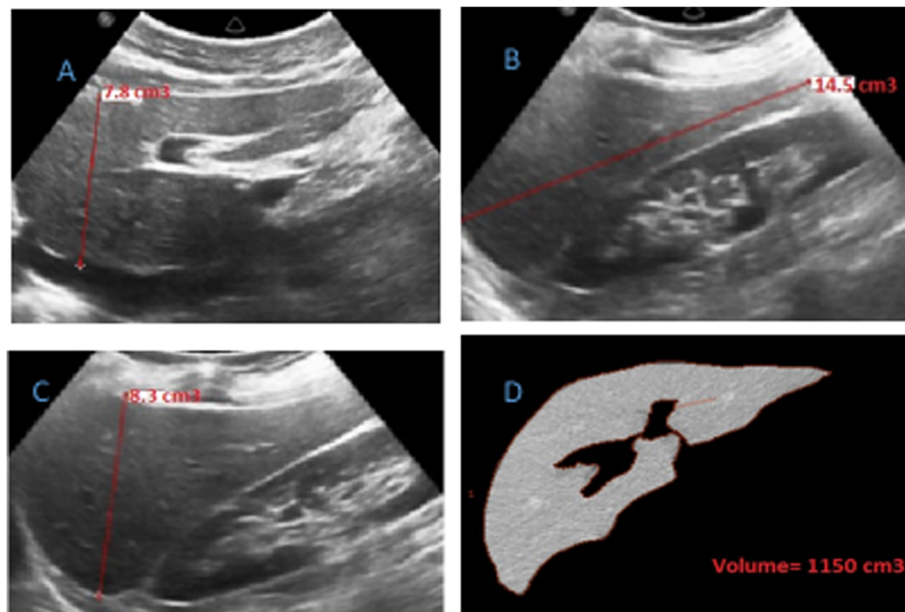


Fig. 3 Female patient, 50 years old. **a** Image 1 represents left lobe of the liver (7.8 cm). **b** Image 2 represents right lobe of the liver (14.5 cm). **c** Image 3 represents right lobe of the liver (8.3 cm). Liver volume (cm³) = 343.71 + (0.84 \times ABC) = 343.71 + (0.84 \times 7.8 \times 14.5 \times 8.3) = 1132.2 cm³. **d** Semi-automated CT volumetry for the same case with liver volume was 1150 cm³

Table 3 Average liver volume by US and CT volumetry as regards sex

	Sex		<i>p</i> value
	Male (<i>N</i> = 50)	Female (<i>N</i> = 50)	
US	1606.10 ± 398.04	1538.10 ± 233.42	0.3
MSCT	1566.00 ± 418.22	1552.50 ± 343.98	0.86

a successful method for liver volumetric assessment because of its limitations, both physically as it is impractical and time-consuming and also those related to a variable reproducibility of the examination which depends mainly on the examiner skills [19]. Also, in the assessment of liver size by simple linear 2D US, there is a lack of standardization of measurement method and adopted cutoff values with the accepted plane of measurement, and its used cutoff values varies from one department to the other, so most of the previous studies did not report its accuracy [10, 17, 20, 21].

As the single linear liver size measurement by ultrasound represents the liver in only one plane, and the morphologic shape of the liver differs among people, Childs et al. determined the set of practical three simple measurement planes using 2D US, and predictive equation was created from these three measurements to determine the liver volume which is more accurate than the liver size [11].

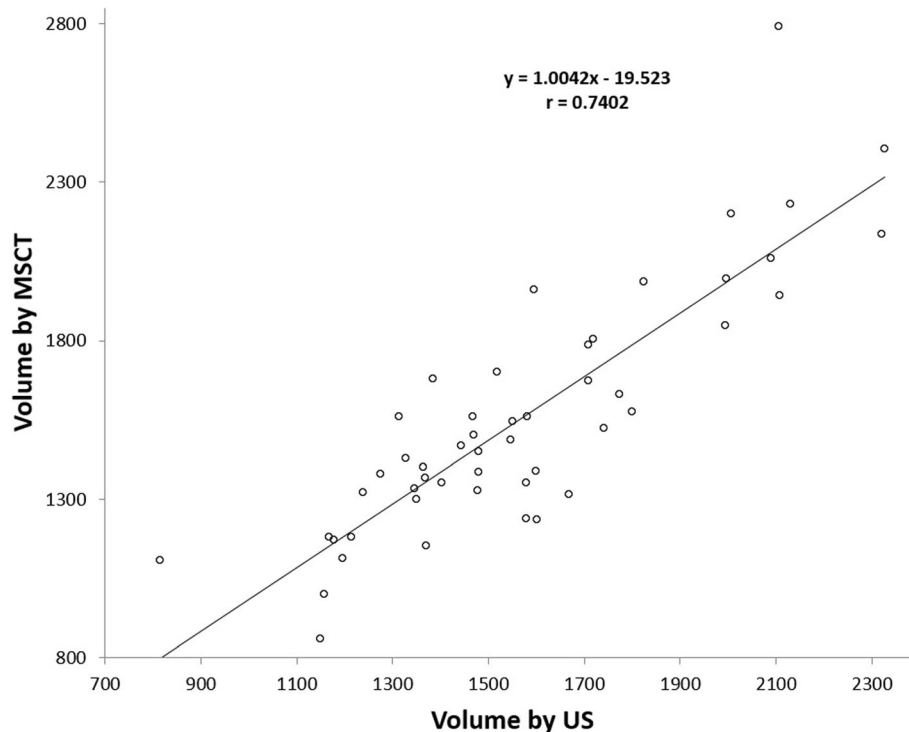
In this study, the 2D US volumetric assessment of the liver in different age groups and different sexes was done by using Childs et al.'s [14] equation, and the results were compared with semi-automated CT volumetric results as a gold standard.

To our knowledge, Childs et al.'s study [19] is the only study which is comparing the results of 2D US volumetric assessment of the liver based on Child et al.'s [14] equation with CT volumetry and reported near perfect agreement ($r = 0.9$) between the two modalities [11, 19]. This agreed with our study which also reported a strong positive correlation ($r = 0.74$) with no statistically significant difference found between them ($p > 0.05$), and no statistically significant difference was found also between them in different age groups and different sexes.

A limitation of this study was that this study was conducted only on normal liver cases, so, in order to generalize the results, further future studies are recommended on diseased liver to validate its accuracy in liver volumetric assessment.

Conclusion

In conclusion, we found that simple linear 2D U/S could be an efficient, accurate, and trustable method for liver volume measurement in clinical practice.

**Fig. 4** Scatter plot diagram is showing correlation coefficient between US and semi-automated CT volumetry with strong positive correlation

Abbreviations

2D US: Two-dimensional ultrasound; 3D US: Three-dimensional ultrasound; CT: Computed tomography; MRI: Magnetic resonance imaging; TLV: Total liver volume

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Authors' contributions

With the submission of this manuscript, I would like to declare that all authors have contributed sufficiently to the scientific work regarding study concepts and design, clinical studies, collection of the data, statistical analysis, manuscript preparation, and editing. All authors have read and approved the manuscript.

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Availability of data and materials

The datasets used or analyzed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

This study was approved by the research ethics committee of the Faculty of Medicine at Assiut University in Egypt on 2018, reference number (17300313), and all patients included in this study gave written informed consent to participate in this research.

Consent for publication

All patients included in this research gave written informed consent to publish the data contained within this study.

Competing interests

The authors declare that they have no competing interests.

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