

A Validation Study of Liver Volumetry Estimation by a Semiautomated Software in Patients Undergoing Hepatic Resections

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Abstract

Purpose The purpose of this study was to validate the use of a semiautomated software for liver volumetry preoperatively by comparing it with the volume of resected specimen in patients undergoing hepatic resections.

Materials and Methods This is a single-center retrospective study of patients who underwent estimation of future liver remnant (FLR) using Myrian XP-Liver which is a semiautomated software for hepatectomy. The estimated resection volume, which is the sum of volume of normal liver to be resected and tumor volume, was compared with actual specimen weight to calculate the accuracy of the software. The statistical analysis was performed with SPSS software version 24.

Results Data on FLR estimation using the semiautomated software was available for 200 out of 388 patients who underwent formal hepatic resections. The median resected volume of surgical specimen was 650 mL (interquartile range [IQR] 364–950), while the median estimated volume using the Myrian software was 617 mL (IQR 362–979). There was significant correlation between estimated resection volume calculated using the semiautomated method and actual specimen weight (p -value < 0.0001) with the Spearman's correlation value of 0.956.

Conclusion The estimated volume of liver to be resected as calculated by the semiautomated software was accurate and correlated significantly with the volume of resected specimen, and hence, the estimation of FLR volume may likely correlate with the true postoperative residual liver volume. In addition, the software-based liver segmentation, FLR estimation, and color-coded three-dimensional images provide a clear road map to the surgeon to facilitate safe resection.

Keywords

- ▶ liver volumetry
- ▶ FLR (future liver remnant)
- ▶ Myrian

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Introduction

With improvements in perioperative care, liver resections are increasingly performed for primary or metastatic liver cancer, with mortality below 5%.^{1,2} Surgeons aim for a total resection of focal liver lesions, but they need to avoid an extensive loss of healthy liver parenchyma, since this can lead to postoperative hepatic failure.³ To perform partial liver resections safely, the determination of the entire preoperative liver volume and the remaining postoperative liver volume is important. After resection, the remnant liver must be able to preserve or recover an adequate synthetic ability to compensate for lost hepatic parenchyma.⁴ Thus, preoperative assessment of liver volumetry has become fundamental in selection of the patient for liver resection. With the advent of multislice computed tomography (CT), many studies have demonstrated a close correlation between intraoperative liver volume or weight measurements and virtually measured liver volumes.⁵⁻⁸ Liver volume detection can be done using manual, semiautomated, and automated tracing method. Manual tracing of liver boundary on CT images though routinely used for liver volume calculation, is time consuming and prone to intra- and interobserver variations⁹ as compared with semi-automated liver segmentation technique.¹⁰

Materials and Methods

A single-center retrospective study of prospectively maintained data of patients who underwent anatomical liver resections between August 2012 and December 2018 was performed. Data on future liver remnant (FLR) estimation using a semiautomated software was available for 200 out of 388 patients who underwent formal hepatic resections in the given time period. The study was approved by the institutional review board. Patients who underwent nonanatomical liver resection and partial hepatectomy for hemangiomas were excluded from this study. During surgery for extracapsular excisions for hemangioma, the tumor shrinks on table during surgery and the volume of resected specimen would be lower than the estimated volume on CT scan. Hence, these patients were excluded from the study.

All patients who underwent liver resection had a triphasic CT evaluation for surgical planning. Most of the patients planned for anatomic resections were operated after estimation of resection and remnant volumes on CT. The estimated FLR was calculated using the Myrian XP-Liver (Intrasense) software by a single radiologist with more than 5 years of experience in hepatobiliary reporting, after discussing the plane of resection with the operating surgeon. The parameters evaluated by the software to estimate FLR included total liver volume, volume of normal liver to be resected, and tumor volume. The estimated resection volume, which is the sum of volume of normal liver to be resected and tumor volume, was compared with actual specimen weight measured immediately after liver resection in the operating room (OR). Surgical specimen weight was used as the gold standard and weight-to-volume ratio of 1:1 was used as a standard

assumption to quantify volume of the resected specimen. The volume of resected specimen was compared with the estimated resection volume calculated using the Myrian software. The statistical analysis was performed with SPSS software version 24 (IBM Corp.).

Scan Parameters and Volumetry

Triphasic CT was performed with a multidetector CT scanner (Siemens SOMATOM Emotion 16, Siemens Healthcare GmbH). Positive oral contrast-medium was not administered. After an initial noncontrast scan, triphasic CT was obtained following an intravenous administration of a iodine contrast medium at a concentration of 300 mg/L (Ultravist 300, Bayer Schering Pharma AG) through an antecubital vein of the arm, using an automatic syringe injector (Stellant, MedRad) at a flow rate of 3 to 4 mLs. The amount of contrast media used was according to the patient's weight, injecting 1.5 mL/kg. In all cases a triphasic examination was performed using a bolus tracking technique; an arterial phase scan of the upper abdomen, performed 10 seconds after the reach of the aortic enhancement threshold (100 Hounsfield unit [HU]) at the level of celiac artery; a portal phase scan of the upper abdomen, performed 35 seconds after the administration of contrast media; and a venous phase scan of the upper abdomen, performed 60 seconds after the administration of contrast media. The following parameters were used: slice thickness 1.5 mm; increment 1.5 mm; tube voltage 110 kV; collimation 16 × 0.6; pitch 1.3; rotation time 0.6 second.

Myrian software was used for semiautomated volumetry which allows quick automatic liver segmentation with volumetry using tissue density difference (HUs). The software allows automatic calculation of the liver vascular territories using density difference in arterial, portal, and venous phase, thus ensuring precise volumetric measurement of the liver parenchyma. Three-dimensional (3D) volumetric display

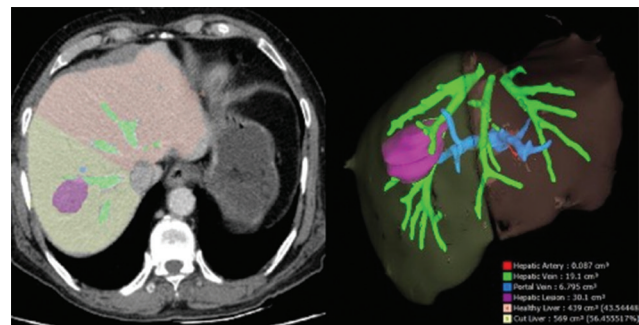


Fig. 1 A 72-year-old male with suspected malignant lesion in the right lobe of the liver was planned for right hepatectomy. (A) Cross-sectional computed tomography (CT) image shows color-coded structures—volume of liver to be resected in light green, future liver remnant in peach color (junction marks the transection plane), hepatic vein in green, and tumor in purple color. (B) Corresponding three-dimensional (3D) image shows transection plane with volume of resecting segment and future liver remnant. The total volume to be resected was obtained by adding tumor volume and cut liver volume and was compared with the volume of the specimen.

with different transparency and color levels are provided for better anatomical understanding (► Fig. 1). Axial images of the arterial, portal, and venous phases were used for CT volumetry. The liver outline, hepatic artery (HA), portal vein (PV), and hepatic veins (HV), and their branches were drawn automatically by the software. After setting seed points into the hepatocaval confluence and the main stem of the PV, the system automatically segments the HV and PV. Those vessels which were not automatically identified by the software were drawn manually. Finally, the transection plane was defined. The volumes of the intrahepatic vessels in the liver area marked for resection were included in the *CT volume*. After volumetric reconstruction of the normal liver parenchyma, tumor, and hepatic vasculature, virtual hepatectomy is performed in accordance with the intended surgical resection plane as decided by the operating hepatobiliary surgeon. The software automatically calculates FLR using the formula

$$\text{FLR} = (\text{Total Liver Volume} - \text{Resected Volume}) / (\text{Total Liver volume} - \text{Tumor Volume})$$

It is expressed in percentage.

Results

Data on FLR estimation using semiautomated software was available for 200 out of 388 patients who underwent formal hepatic resections in the given time period (► Tables 1 and 2). The median resected volume of surgical specimen was 650 mL (with interquartile range [IQR] 364–950), while median estimated volume using the Myrian software was 617 mL (with IQR 362–979). The mean postoperative resected volume was 801.8 g and the mean estimated volume was 817.57 mL. In the evaluation of operative resection volume, Spearman's correlation test showed significant correlation between the estimated specimen volume recorded using the Myrian software with the actual value recorded in OR (p -value < 0.0001) with correlation coefficient (r) value of 0.956 (► Fig. 2). The difference between estimated and actual specimen volume had median value of 38 mL (with IQR 9.25–105).

Table 1 Demographic and surgical details

Age distribution	15–79 y
Male:Female	141:59
Mean age for male	53.5 y
Mean age for female	49.8 y
Right hepatectomy	93
Right extended hepatectomy	12
Right posterior sectionectomy	7
Right anterior sectionectomy	1
Left hepatectomy	38
Left lateral hepatectomy	31
Left extended hepatectomy	8
Central hepatectomy	10

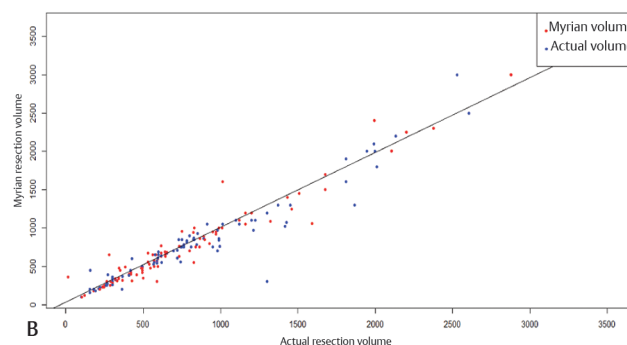
Table 2 Distribution of cases as per histopathology

Hepatocellular carcinoma	87 (43.5%)
Metastases	70 (35%)
Cholangiocarcinoma	27 (13.5%)
Hepatic adenoma	3
Carcinoma gallbladder	2
Angiomyolipoma	1
Embryonal sarcoma	1
Hepatoblastoma	1
Benign biliary cystadenoma	1
Pyogenic abscess	2
Hydatid cyst	2
Nontubercular granulomatous infection	1
Tuberculosis	1
Immunoglobulin G4-related pseudotumor	1

Correlations			MYRIANResectVol	ActualResVol
Spearman's rho	MYRIANResectVol	Correlation Coefficient	1	.956**
		Sig. (2-tailed)		0
		N	200	200
	ActualResVol	Correlation Coefficient	.956**	1
		Sig. (2-tailed)	0	
		N	200	200

** Correlation is significant at the 0.01 level (2-tailed).

A



B

Fig. 2 Scatter plot (A) and corresponding table (B) showing correlation between estimated resection volume using semiautomated method and actual resection volume. The correlation coefficient (r) is 0.956. Red dots represent the Myrian volume and blue dots the actual volume. Volume along the X-axis represents specimen volume, while the Y-axis represents estimated volume by the Myrian software.

Discussion

Of various organs, the liver is one of the most difficult to segment virtually due to its varying shape. Ultrasound, CT, or magnetic resonance imaging (MRI) has been used to estimate hepatic volume preoperatively prior to liver resection and transplantation.

The use of CT volumetry on cadavers was first performed by Heymsfield et al⁵ in 1979 and the accuracy of this method was found to be within 5% of water displacement volumetry. Since then, various studies have shown preoperatively measured liver volumes using CT and MRI correlated with intraoperative volume and weight measurement. Conversion factors have been suggested to compensate for overestimation

of preoperative volume which could be due to blood perfusion.^{3,11} Median liver density estimated by intraoperative weight and volume measurement averages from 1.05 to 1.07 g/mL.^{11,12}

Various automatic and semiautomatic segmentation techniques have been used to measure preoperative volumes because they had the advantage of requiring substantially lesser time compared with manual volumetry.¹³ Manual and automated volumetry softwares have been used for estimation of liver volumes and vascular volumes of liver donors prior to transplantation.^{9,14} CT is more commonly used, as it is more accessible, provides higher spatial resolution, and has short acquisition time.⁹ Manual liver segmentation used for calculation of preoperative resection volumes however relies highly on the user performing the segmentation.¹⁵ It is done by the contouring of pixels along the boundary of the liver; or by in-painting of the liver parenchyma on sequential CT slices with the use of paintbrush tools. Once the liver has been identified on each slice, postprocessing software is used to generate liver volume. There is no exclusion of the vessels enclosed by the parenchyma in the manually painted liver. This exercise is repeated for calculation of lesion volume. The user then has to separately paint the volume of the liver which would be resected depending on the intended resection plane. This process has to be repeated many times if there are multiple possible resection planes. Manual segmentation is thus time consuming and may take up to 90 minutes per patient.¹⁶ It is also prone to intra- and interobserver variability given its inherent subjectivity.¹⁵ As a result, for a high volume center, manual segmentation is not ideally suited to guide patient selection and treatment planning.

Semiautomated and automated segmentation techniques require minimal initialization from the user; the software provides most of the optimization. The semiautomated softwares mainly employ intensity-based techniques, using density difference in arterial, portal, and venous phase allowing a precise automatic volumetric measurement of the liver parenchyma. Since the intrahepatic vessels are color coded, liver subsegmentation can be performed according to vascular supply (i.e., PVs and HAs) or drainage (i.e., HVs) rather than the standard Couinaud classification system which does not take into account the different anatomical liver variants seen in individual patients. This is especially useful for performing parenchyma sparing anatomical resections in cirrhotic patients by allowing the surgeon to remove the tumor with adequate margins without removing excess of normal liver parenchyma.

A study done for evaluation of FLR by automated and semiautomated methods in hepatectomy patients ($n = 36$) has shown the volumes using both techniques had a significant difference but a high degree of correlation with actual intraoperative specimen volume.¹⁷ Another study ($n = 66$) evaluated correlation between preoperative planned remnant liver volume and postoperative actual remnant liver volume determined from early postoperative scan using a semiautomated method and found significant correlation.¹⁸

In this study, validation of the semiautomated software was tried by comparing the preoperative estimated resection

volume with the volume of the resected surgical specimen. Assuming that the density of the liver is 1 kg/m³, the median resected volume of surgical specimen was found to be 650 mL. The median estimated volume calculated using the Myrian software was 617 mL and the difference between estimated and actual volume had a median value of 38 mL. Spearman's correlation test showed significant correlation (p -value < 0.0001) between the estimated specimen weight recorded using the Myrian software with that of the actual specimen weight with correlation coefficient (r) value of 0.956.

Liver segmentation by the Myrian software and the color-coded 3D images obtained are more comprehensible for the operating surgeon, who can easily guide or modify the resection plane. Multiple possible resection planes can be drawn and resection volumes for each can be calculated easily if there are a surgical dilemma and provide a clear road map for the surgeon to perform a safe liver resection.

Since the volume of the resected specimen closely correlates with the estimated volume estimated by Myrian software, it may be assumed that the estimated FLR would also be accurate and reliable. However, a study comparing the FLR estimated by the Myrian software with surgical outcome is required to validate this assumption.

The limitation of this study is that, the volume of surgical specimen was calculated by standard assumption of weight-to-volume ratio of liver to be 1:1 and the actual density of specimen to calculate volume was not determined. Also, the influence of cirrhosis and tumor histopathology on the density of resected specimen and volume estimation by the Myrian software was not evaluated.

Conclusion

The semiautomated software-based preoperative liver volumetry was accurate and showed significant correlation when compared with resected surgical specimen. The software-estimated FLR volume may hence correlate with the true residual liver volume and be a valuable tool to select potential surgical candidates for liver resection. The liver segmentation and color-coded 3D images provides a clear road map to the surgeon to facilitate safe resection.

Conflict of Interest

None of the authors have any conflicts of interest associated with this publication, and there has been no significant financial support for this work that could have influenced its outcome.

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