Imaging-Based Volumetry of the Liver: Where Does It Stand?

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Learning objectives

Liver volume estimation is considered an integral part in the pre-operative assessment of patients undergoing liver resection as well as for those undergoing liver transplantation. Considerations would include pre-operative baseline liver function, patient size and post-operative residual liver volume (future remnant liver volume; FRLV). These impact on the decision to perform major liver resections, and in the appropriate context, the need for portal vein embolisation to increase the FRLV.

We first review the evidence supporting the use of imaging-based volumetry of the liver in clinical practice. We shall then proceed to discuss the strengths and limitations of using imaging to estimate liver volumes, with specific references to the various methods that have been described in the literature. Finally, we suggest potential ways to improve on the existing methods that may enable imaging-based volumetry to gain greater ground in clinical practice.

Background

Computed tomography (CT) volumetry has been widely used in the preoperative volumetric assessment of the liver, particularly in patients planned for major hepatic resection due to primary liver tumours or metastases, as well as for liver transplantation.

It is imperative to achieve accurate determination of the liver volume especially in patients with chronic liver disease or cirrhosis where the size of the liver is an important prognostic factor. The liver volume is one of the key factors in the selection of appropriate donors, especially in a patient undergoing living related liver transplantation (LRLT). CT volumetry also plays a part in determining surgical resectability of hepatic lesion(s) by assessing the safety limit for remnant liver volume. In addition, volumetric assessment is used after portal vein embolization (PVE) in the evaluation of the increase in FRLV. The use of CT volumetry is also seen in postoperative determination of residual liver volume, which in part, predicts the likelihood of liver failure and liver failure-related mortality.

Volumetric assessment is usually performed with cross-sectional CT imaging. The use of other imaging modalities such as magnetic resonance imaging (MRI) and ultrasound have also been described, and have similarly shown to yield reliable organ volume measurements in the light of appropriate scanning protocols.
Imaging findings OR Procedure details

Manual vs Semi-automated vs Automated means of CT volumetry

CT volumetry has been traditionally performed by manual tracing of the hepatic contours and summation of the liver area on each axial section, usually by a radiologist. However, such manual methods are heavily operator-dependent and require considerable amount of time and attention. Automated and semi-automated ways of volumetric measurements have been carried out \cite{1,2,3,4}. Various techniques and algorithms have been described for automated volumetry, including 3D active contour segmentation \cite{1} and geodesic active contour segmentation coupled with level set algorithms \cite{3}. One of such technique involves the estimation of the mean CT value of the liver and selection of the initial candidate regions of the liver on each slice using estimated CT value of the liver. The liver is separated from other adjacent organs via the analysis of edge information inside the initially estimated liver. A three-dimension (3D) image of the liver is subsequently reproduced for the calculation of liver volume \cite{4} [Fig 1]. Semi-automated methods allow the correction of automated segmentation, hence allowing more flexibility and autonomy over the volumetric determination [Fig 2].

The volumetric results have yielded excellent agreement with manual volumetric results. The calculated volumes and intraoperatively measured graft volumes have also correlated significantly. The average user time for automated volumetry was 0.57 ± 0.06 min/case, whereas those for semi-automated and manual volumetry were 27.3 ± 4.6 and 39.4 ± 5.5 min/case respectively\cite{1}. This implies an effective time-saving measure of more than 30 minutes per case if one switched from manual to automated means of volumetric assessment.

Contour-tracing by means of a freehand electromagnetic pen tablet has been explored instead of the standard optical mouse method \cite{5}. There were comparable accuracy and precision in the two methods. The mean segmentation time per patient was significantly shorter with use of freehand electromagnetic pen contourtracing method, and this could represent a new technological development in reducing the time spent on tracing the liver boundaries. There is however limited literature on the use of such novel technique.

Slice Thickness

There is a relationship between the slice thickness and the calculated liver volumes \cite{6}. Liver volumes calculated from 2.5mm-thick or thicker images are significantly smaller than liver volumes calculated from 3D images (0.625mm-thick slices), whereas volumes
calculated from 3D images were significantly larger than volumes calculated from thicker images. On the same note, a maximum error of 5% in the calculated graft volume should be expected when 5mm-thick slices are used. However, if precise determination of the liver volume is critical, especially in patients with diseased livers, 3D images should be considered.

**The Use of Personal Computer and Software in Volumetric Assessment**

Volumetric measurements of the liver have also been described beyond the use of dedicated professional software. Various authors used easily-accessible, easily-downloadable software such as OsiriX[^7^], Adobe Photoshop[^8^], ImageJ[^9^] to measure hepatic volumes, and these have found to have good correlation with conventional CT volumetry as well as with intra-operative graft volume. The use of these software on a personal computer have also been explored and found to be feasible[^8^].

Accurate volumetric measurements have been successfully performed by other non-radiology medical personnel[^8^] - a study showed a small interobserver variability in the determination of total liver volumes, resection volumes and tumor volumes using OsiriX software by surgical trainees when compared to a CT scanner-linked Aquarius intuition software by a radiologist. This implies greater empowerment and self-efficacy of non-radiology colleagues, particularly the surgeons, in the determination of the liver volume prior to surgical intervention as well as in the follow-up of cases after hepatic resections to chart liver regeneration.

**The value of other imaging modalities in volumetric assessment**

The use of other imaging modalities such as ultrasound and magnetic resonance imaging (MRI) have also been reported. There is a strong positive correlation in the virtual liver volume measurement using CT and MRI[^10,11^].

Good concordance is found between 3D-ultrasound and 3D-CT volumetry; however the use of conventional 2-dimensional (2D) ultrasound has shown to be less precise compared to 3D-ultrasound and 3D-CT volumetry.

**Functional assessment vs Morphological assessment**

Other than preoperative assessment of liver volume, there is increasing focus on the use of imaging modalities in the assessment of the FRLV to predict the likelihood of
post-operative liver failure after major hepatic resection, particularly in patients with pre-existing chronic liver disease.

The use of CT volumetry has been found to be inferior to 99m-Technetium-galactosyl human serum album scintigraphy (Tc99m-GSA)\textsuperscript{[12,13]} and 99m-Technetium-mebrofenin hepatobiliary scintigraphy (Tc99m-mebrofenin HBS)\textsuperscript{[14,15,16]} in the determination of the risk of liver failure and its related mortality after hepatectomy through assessment of the functional status of the remnant liver. In a multivariate analysis done by Dinant et al\textsuperscript{[16]}, uptake of Tc99m-mebrofenin was the only significant factor associated with liver failure. The volume of the future remnant liver was found not to be significantly associated with any of the outcome parameters.

**Future Remnant Liver Volume**

Pre-operative portal vein embolization (PVE) has been widely regarded as an effective means to increase future remnant liver volume (FRLV) by inducing hypertrophy of the remnant liver [Fig 3], particularly in patients with inadequate remnant liver volume who require major or extended hepatectomy\textsuperscript{[19]}.

The functional capacity of the liver is commonly assessed with 99mTc-mebrofenin single-proton emission computed tomography (SPECT). The hepatic function varies according to the health of one's liver. For people with normal healthy liver parenchyma, the functional liver volume is comparable to the total liver volume measured by CT volumetry. However, there is a discrepancy in the concordance of functional and morphological imaging modalities in people with compromised livers, where the future remnant liver function per cm\textsuperscript{3} of liver volume was significantly less. In addition, liver function was not distributed homogeneously, with the diseased segments to be resected relatively more affected.

On a similar note, the safety threshold for hepatic resection is heavily dependent on the diseased state of the liver. Whilst patients with normal liver parenchyma require >27% of functional liver volume, the requirement is >40% in patients with high-grade steatosis and even more so of >50% of total functional liver volume in those with cirrhosis\textsuperscript{[20]}.

**Paediatric Population**

The preoperative estimation of the graft volume by CT volumetry tends to be larger than intraoperative measured graft weight. The use of an age-adjusted formula is useful to
account for the overestimation of graft volume, particularly in the younger donors. One example of such formula: age-adjusted graft volume = 70.767 + (graft volume estimated with CT volumetry) + (1.298 x donor age) [21].

Images for this section:

**Fig. 1:** 3D-reconstruction of the liver
Fig. 2: Semi-automated CT Volumetry: with stroke and cutting contour techniques

Fig. 3: Pre- and Post-Embolization of the Portal Vein
Fig. 4: CT images of a 56 year old woman with hepatic metastases. Scheduled for extended right hepatectomy. (a)-(b): pre-PVE (c)-(d): one month post-PVE and coiling of segment 7/8. There is hypertrophy of the left lobe of the liver.
Conclusion

Future Directions

- The increasing use of semi-automated and automated methods as efficient means of saving manpower and time, without compromising on the precision of the study.
- Easy accessibility and determination of volumetric assessment in the comfort of one's home using personal computer and easily-downloadable software.
- The synerism of both functional and morphological imaging modalities in assessing future remnant liver and in predicting the likelihood of post-operative complications

Conclusion

Imaging-based volumetry of the liver is vital in the pre-operative planning for major hepatic resection or liver transplantation as well as in the determination of future remnant liver volume. As the techniques evolve and become more user-friendly, radiologists should be aware of its potential applications in order to utilise it appropriately.

The morphological volumetric assessment of the liver should be combined with the use of functional imaging modalities in giving rise to a more accurate functional liver volume, hence preventing post-operative liver failure and its associated mortality.

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References


