Clinical Radiology 69 (2014) 887–895

Contents lists available at ScienceDirect

Clinical Radiology

journal homepage: www.clinicalradiologyonline.net

Review

CT volumetry of the liver: Where does it stand in clinical practice?

M.C. Lim [a,*], C.H. Tan [a], J. Cai [b], J. Zheng [b], A.W.C. Kow [c]

[a] *Department of Diagnostic Radiology, Tan Tock Seng Hospital, 11 Jalan Tan Tock Seng, Singapore 308433, Singapore*
[b] *School of Computer Engineering, Nanyang Technological University, Block N4 Nanyang Avenue #02a-32, Singapore 639798, Singapore*
[c] *University Surgical Cluster, National University Hospital, 5 Lower Kent Ridge Road, Singapore 119074, Singapore*

ARTICLE INFORMATION

Article history:
Received 2 October 2013
Received in revised form
14 December 2013
Accepted 17 December 2013

Imaging-based volumetry has been increasingly utilised in current clinical practice to obtain accurate measurements of the liver volume. This is particularly useful prior to major hepatic resection and living donor liver transplantation where the size of the remnant liver and liver graft, respectively, affects procedural success and postoperative mortality and morbidity. The use of imaging-based volumetry, with emphasis on computed tomography, will be reviewed. We will explore the various technical factors that contribute to accurate volumetric measurements, and demonstrate how the accuracies of these techniques are influenced by their methodologies. The strengths and limitations of using anatomical imaging to estimate liver volume will be discussed, in relation to laboratory and functional imaging methods of assessment.

Introduction

Liver volume estimation is undertaken in the preoperative assessment of patients undergoing liver resection or liver transplantation. In the assessment of suitability for surgery, key considerations include preoperative baseline liver function, patient size, standardized liver volume (SLV), and postoperative residual liver volume (future liver remnant or FLR). These factors are also applicable, in the appropriate context, for a subset of patients who may require portal vein embolization (PVE) to increase FLR volume. Volumetry may also be important for post-therapy assessment, such as following liver transplant to assess graft regeneration and treatment response assessment of liver malignancies.

Volumetric determination should be a multidisciplinary approach. The need for close communication between the surgeon and the radiologist is vital in the determination of the choice of surgical plane (such as hemi-hepatectomy versus extended hemi-hepatectomy), assessment of resectability and the visualization of tumour extent. Prior careful assessment of the liver function is also vital, as a diseased liver (e.g., steatosis and cirrhosis) requires significantly more residual volume as compared to a normal healthy liver.

Computed tomography (CT) volumetry (CTV) has been widely used as a method for the preoperative volumetric assessment of the liver, for the indications as described above. The use of other imaging methods, such as magnetic resonance imaging (MRI) and ultrasound, have also been explored and have shown reliable organ volume measurements when the appropriate scanning protocols are

* Guarantor and correspondent: M.C. Lim, Tan Tock Seng Hospital, 11 Jalan Tan Tock Seng, Singapore 308433, Singapore. Tel.: +65 63578111; fax: +65 63578158.
E-mail address: chitin86@yahoo.com.sg (M.C. Lim).

0009-9260/$ – see front matter © 2014 The Royal College of Radiologists. Published by Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.crad.2013.12.021

employed. The strengths and limitations of the various imaging modalities for liver volume estimation are discussed subsequently.

Clinical applications of CTV

Liver resection

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 remnant liver becomes even more important as a prognostic factor. As the presence of underlying liver disease can potentially influence the surgical resectability of a lesion, accurate determination of any hepatic parenchymal disease (particularly cirrhosis) is therefore vital. There are many non-invasive methods available in the evaluation of liver cirrhosis, such as ultrasonic transient elastography (Fibroscan).[1] However, histological diagnosis via liver biopsy remains the reference standard for the diagnosis of liver cirrhosis, and should be considered in the subset of patients with equivocal laboratory and imaging findings.

The FLR-to-SLV ratio is used as an indicator in predicting the likelihood of postoperative liver failure after major hepatic resection, particularly in patients with pre-existing chronic liver disease. The SLV is based upon the regression analysis of normal population (typically transplant donors), and in which a formula can be calculated either from a patient's body weight (BW) or body surface area (BSA). 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.[3]

In patients with normal livers, an SLV <20% following major surgical resection has been found to be associated with higher postoperative morbidity and liver insufficiency, including the length of stay in the intensive care unit.[4] The exact FLR can be patient-specific and a range of cut-off percentages have been proposed in various publications. For example, in a prospective study, Ferrero and colleagues found that an FLR of approximately 26.5% is required for patients with a healthy liver.[5] However, for patients with underlying liver disease, it is generally accepted that the FLR required is considerably larger than those with a normal liver given the impaired baseline function of the hepatocytes. In order to ensure surgical success and to reduce significant morbidity and mortality, a patient with cirrhosis will require an FLR of >50% whereas the requirement is >40% in patients with high-grade steatosis.[2,5,6] To overcome the potentially low FLR after liver resection, PVE can be performed preoperatively to induce contralateral hypertrophy and, therefore, reduce the loss of liver mass following surgery.[2]

Postoperative infection is also a major cause of mortality. Increased risk of severe infection is inversely correlated with FLR.[7] In the study of Schindl et al.[7] on 104 patients who underwent liver resection, analysis of the subgroup of patients with smaller relative residual liver volume showed a significant relation between severe hepatic dysfunction and infection, suggesting that there may be a relationship between liver function, innate immunity, and susceptibility to infections.

Living donor liver transplantation

The liver volume is also a key factor in the selection of the appropriate individual for living donor liver transplantation (LDLT). Imaging of the recipient should be carried out as close to the time of planned transplantation as possible so as to obtain an accurate reflection of the recipient's disease state, particularly if there is underlying malignancy as tumour can rapidly progress. Any vascular invasion or thrombosis should be readily identified, as this influences the plausibility of transplantation. Additionally, proximity of the tumour to the main hepatic and portal vasculature as well as the central bile ducts should be highlighted. In patients with end-stage cirrhosis, imaging should actively seek to exclude hepatocellular carcinoma (HCC). CT of the thorax and abdomen should be acquired at the same sitting to rule out metastatic disease or concomitant extra-hepatic primary malignancy, should a hepatic tumour be present.

Although the imaging findings of the recipient have no significant impact on donor selection, precise assessment of the donor liver volume is crucial in determining whether the donor is suitable for LDLT to ensure safety for both donor and recipient. Preoperative imaging is required to ensure there is no underlying focal or diffuse liver disease that may make transplantation unsuitable, such as steatosis, cirrhosis, and focal benign or malignant neoplasms.

For accurate liver volume estimation, a good understanding of intrahepatic vascular and biliary anatomy is important. Sound knowledge of the surgical procedure is required for accurate evaluation of the donor liver volume. The key anatomical variants that may potentially influence the surgical techniques should be highlighted.[8] For example, typical anatomy of the hepatic arterial is only seen in 55–61% of the population. Common variants include replaced left hepatic artery from the left gastric artery and replaced right hepatic artery from the superior mesenteric artery as well as accessory right or left hepatic arteries.[9] Precise details of the vascular anatomy and its associated territories can be obtained via angiography or through the use of personalized computer analysis software, such as the LiverAnalyzer (MeVis Distant Services, MeVis Medical Solutions, Bremen, Germany; Fig 1).

Using CTV there is generally good correlation of the estimated volume with graft weight obtained.[10] A study by Nakayama et al.[11] showed that the mean weight of an adult liver was 881.1 ± 249.8 g, whereas the mean measured volume of the liver was 956.99 ± 280.1 cm^3.[11]

For an adult donor, a remnant liver volume of 30% for the donor is considered to be the minimum threshold for transplantation to proceed, providing that there is no steatosis or other underlying liver disease.[12] Small-for-size syndrome occurs when the graft size is too small for the