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ORIGINAL ARTICLE

Comparison of techniques for volumetric analysis of the future liver remnant: implications for major hepatic resections

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Abstract

Objective: The purpose of this work was to compare measured and estimated volumetry prior to liver resection.

Methods: Data for consecutive patients submitted to major liver resection for colorectal liver metastases at two centres during 2004–2012 were reviewed. All patients underwent volumetric analysis to define the measured total liver volume (mTLV) and measured future liver remnant ratio (mR_{FLR}). The estimated total liver volume (eTLV) standardized to body surface area and estimated future liver remnant ratio (eR_{FLR}) were calculated. Descriptive statistics were generated and compared. A difference between mR_{FLR} and eR_{FLR} of $\pm 5\%$ was considered clinically relevant.

Results: Data for a total of 116 patients were included. All patients underwent major resection and 51% underwent portal vein embolization. The mean difference between mTLV and eTLV was 157 ml ($P < 0.0001$), whereas the mean difference between mR_{FLR} and eR_{FLR} was -1.7% ($P = 0.013$). By linear regression, eTLV was only moderately predictive of mTLV ($R^2 = 0.35$). The distribution of differences between mR_{FLR} and eR_{FLR} demonstrated that the formula over- or underestimated mR_{FLR} by $\geq 5\%$ in 31.9% of patients.

Conclusions: Measured and estimated volumetry yielded differences in the FLR of $\geq 5\%$ in almost one-third of patients, potentially affecting clinical decision making. Estimated volumetry should be used cautiously and cannot be recommended for general use.

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Introduction

Major hepatectomy is commonly used in the treatment of primary and secondary liver malignancies. Following major hepatectomy, liver insufficiency or 'small-for-size syndrome' is associated with significant morbidity and mortality.[1]

Liver insufficiency is a clinical syndrome whereby the remnant liver fails to sustain adequate organ function, leading to hyperbilirubinaemia, coagulopathy, ascites, encephalopathy and hypoalbuminaemia. It may lead to further renal and/or respiratory failure, infectious complications, and ultimately to postoperative death.[1,2] Despite this general understanding of the syndrome, it remains ill defined, as evidenced by the varying interchangeable terminology utilized in the literature. It has been referred to as liver 'insufficiency', 'failure' and 'dysfunction', as well as 'small-for-size syndrome'. At least four groups have attempted to define this syndrome based on various clinical parameters, in two instances utilizing postoperative death from liver failure as an objective outcome.[3–6]

Despite varying definitions, there is consensus in the literature regarding the importance of maintaining adequate remnant volume following liver resection. Although other factors

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are thought to influence post-resection liver function, such as the health of the remaining parenchyma, age, diabetes, chemotherapy-associated injury, operative blood loss and cholestasis,[2] most authors agree that a minimal future liver remnant (FLR) exists for safe resection. In a young and otherwise healthy patient with normal underlying liver parenchyma, commonly reported FLR cut-off values typically represent 20–30% of the patient's total liver volume (TLV).[4,7–9]

Several techniques exist to measure the FLR. Most centres measure liver volumes directly on cross-sectional imaging and compute the remnant to TLV ratio using only functional non-tumoral liver as representative of TLV. Alternatively, another technique has been described by Vauthey's group and is often used in practice.[10] It consists of estimating the TLV based on a patient's body surface area (BSA), measuring the future liver volume on cross-sectional imaging, and then calculating the percentage of the FLR that can now be considered to be standardized to the patient's BSA. Given that these two techniques are inherently different, the objective of this work was to determine the accuracy and variability of each volumetric method in the context of major hepatic resection.

Materials and methods

Patients

A retrospective review of the medical records of consecutive patients submitted to major liver resection at two major tertiary hepatobiliary units in Canada and the Netherlands, respectively, during 2004–2012 was carried out. Approval for this study was sought and obtained from the Ethics Committee of the Centre de Recherche du Centre Hospitalier de l'Université de Montréal (CR-CHUM 12.221). In the Netherlands, research ethics approval was waived for this type of study by the Academic Medical Centre Ethics Board.

Patient selection criteria were defined *a priori*, before any data acquisition or analysis. Inclusion criteria required that: (i) the patient had undergone major liver resection (three or more segments)[6] for metastatic colorectal cancer, and (ii) the patient had undergone volumetric analysis to determine the volume of his or her FLR. Exclusion criteria ruled out data for: (i) patients for whom volumetric data measured prior to any liver surgery or intervention [e.g. staged resection or portal vein embolization (PVE)] were not available; (ii) patients for whom data on height and weight were not available, and (iii) patients with chronic liver disease. These criteria were chosen to define a homogeneous study population in which volumetric analysis would not be affected by hepatic remodelling from prior liver interventions, chronic liver disease, or biliary tract dilation. All patients were thus pre-PVE or pre-staged resection, if necessary, and were thus expected to yield a comparison of volumetric assessment techniques that was as objective as possible. At the Canadian centre, all measurements were recorded within a prospective database for clinical utilization. At the Dutch centre, measurements included both prospectively recorded volumes and some retrospective volumes generated from the original pre-intervention imaging. At both centres, volumetry was utilized commonly for major hepatectomy at the surgeon's discretion.

Data on patient and tumour characteristics included details of age, gender, weight, height, number of liver lesions, and pathological changes within the peritumoral liver parenchyma. Treatment characteristics recorded included details of neoadjuvant chemotherapy, type of major liver resection, and requirement for PVE.

Liver volume measurements

At the Canadian centre, all volumetric analyses were performed by one trained radiology technician (AB) during the entire duration of the study. Senior liver surgeons verified all measurements and utilized the data for clinical practice (FV-M, RL, MD). A dedicated GE Advantage Workstation 4.2 (GE Healthcare, Inc., Waukesha, WI, USA) was used for this work. For each patient, relevant volumes were measured using portal phase computed tomography (CT) or magnetic resonance imaging (MRI) of the liver. When both CT and MRI scans were available, the CT scan was used preferentially. Measured total liver volume (mTLV) was obtained by delineating the liver contour manually on every cut with slice thickness of 5 mm or every one or two cuts with slice thickness of $\leq$3 mm. Volume was calculated by the software based on the total surface area measured on each imaging cut and the distance between slices. Total tumour volume (TV) and FLR volume were measured in a similar fashion. The caudate lobe was always included in volume measurements. Couinaud segmental anatomy was defined in the usual fashion on the basis of portal vein and hepatic vein anatomy.[11] Intrahepatic portal pedicles and hepatic veins were included within the tracings. The gallbladder, extrahepatic portal pedicles, extrahepatic hepatic veins and inferior vena cava were excluded from volume measurements according to the accepted method of segmenting the liver.[10]

At the Dutch centre, all volumetric analyses were performed by one surgical trainee experienced in performing volumetric measurements (KPC) and verified by an experienced radiologist (KPvL). Integrated software (Mx-View 3.52; Philips Medical Systems BV, Best, the Netherlands) was used to calculate all liver volumes. All relevant volumes were measured using portal phase CT scans with 5-mm slice thickness. Total volume, FLR volume and mTLV were measured using the same technique as at the Canadian centre.

Volumetric analysis

For each patient, relevant liver volumes were measured 'manually' using the technique outlined above (mTLV, TV and FLR volume). From these data, the measured FLR ratio (mR_{FLR}), expressed as the predicted percentage of liver remaining after resection, was calculated as: mR_{FLR} = (FLR volume/mTLV − TV) × 100.