Liver Planning Software Accurately Predicts Postoperative Liver Volume and Measures Early Regeneration

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BACKGROUND: Postoperative or remnant liver volume (RLV) after hepatic resection is a critical predictor of perioperative outcomes. This study investigates whether the accuracy of liver surgical planning software for predicting postoperative RLV and assessing early regeneration.

STUDY DESIGN: Patients eligible for hepatic resection were approached for participation in the study from June 2008 to 2010. All patients underwent cross-sectional imaging (CT or MRI) before and early after resection. Planned remnant liver volume (pRLV) (based on the planned resection on the preoperative scan) and postoperative actual remnant liver volume (aRLV) (determined from early postoperative scan) were measured using Scout Liver software (Pathfinder Therapeutics Inc.). Differences between pRLV and aRLV were analyzed, controlling for timing of postoperative imaging. Measured total liver volume (TLV) was compared with standard equations for calculating volume.

RESULTS: Sixty-six patients were enrolled in the study from June 2008 to June 2010 at 3 treatment centers. Correlation was found between pRLV and aRLV ($r = 0.941$; $p < 0.001$), which improved when timing of postoperative imaging was considered ($r = 0.953$; $p < 0.001$). Relative volume deviation from pRLV to aRLV stratified cases according to timing of postoperative imaging showed evidence of measurable regeneration beginning 5 days after surgery, with stabilization at 8 days ($p < 0.01$). For patients at the upper and lower extremes of liver volumes, TLV was poorly estimated using standard equations (up to 50% in some cases).

CONCLUSIONS: Preoperative virtual planning of future liver remnant accurately predicts postoperative volume after hepatic resection. Early postoperative liver regeneration is measureable on imaging beginning at 5 days after surgery. Measuring TLV directly from CT scans rather than calculating based on equations accounts for extremes in TLV. (J Am Coll Surg 2014;219:199–207. © 2014 by the American College of Surgeons)

During the past several years, partial hepatectomy has emerged as the most effective and the only potentially curative therapy for many primary and secondary hepatic tumors.[1,2] The therapeutic advantage of resection over other treatments is now clear, but has only manifested as the marked improvements in safety have been realized.

Disclosure Information: Drs Clements and Miga received payments for patents and licensing fees from Pathfinder Therapeutics Inc. Dr Miga holds less than 1% equity in Pathfinder Therapeutics Inc. All other authors have nothing to disclose.

Drs Dumpuri, Clements, Miga, and Simpson were supported by the NIH/National Cancer Institute grant R01 CA162477. Dr Stefansic was supported by NIH SBIR CA119502. Memorial Sloan-Kettering Cancer Center, University of Pittsburgh Medical Center, and University of Florida received support for the study from Pathfinder Therapeutics Inc. through NIH SBIR CA119502. Also, this study was supported by NIH/National Cancer Institute Cancer Center Support grant P30 CA008748 (to Memorial Sloan-Kettering Cancer Center).

Received August 1, 2013; Revised February 12, 2014; Accepted February 14, 2014.

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ISSN 1072-7515/14/$36.00
http://dx.doi.org/10.1016/j.jamcollsurg.2014.02.027

Abbreviations and Acronyms

aRLV = actual remnant liver volume
BSA = body surface area
CI = confidence interval
IQR = interquartile range
MSKCC = Memorial Sloan-Kettering Cancer Center
pRLV = planned remnant liver volume
TFLV = total functional liver volume
TLV = total liver volume
UPMC = University of Pittsburgh Medical Center

Full recovery from major hepatic resection requires a healthy, well-perfused liver remnant that is capable of regenerating to its preresection volume. A better appreciation of the adequacy of the future liver remnant size and quality has represented an important safety advance in hepatic resectional surgery. Several studies have shown that the percentage of functional liver parenchyma remaining after major hepatic resection is an important predictor of postoperative hepatic dysfunction and morbidity.[3-6]

In the past, liver volumetry was calculated either by using equations involving height and weight[7,8] that fail to account for individual variability, or by manually designating liver parenchyma and tumor boundaries from cross-sectional imaging studies,[3,9] which is time consuming. In the last decade, automated and semi-automated methods of demarcating the liver from neighboring structures have been the subject of intense investigation,[10] with some clinical adoption.[3,11,12] Software tools now exist for computing hepatic volumetry and defining surgical resection margins on virtual anatomy[13,14]; however, whether these utilities accurately predict postoperative volume is an unresolved question. Studies that correlate virtual resection volume with the volume of the resected mass do so by weighing the mass after resection and applying a conversion factor from weight to volume (1 g = 1 mL)[15] or by acquiring postoperative scans more than a week after surgery,[11] after volume changes might have occurred.

This multicenter study evaluates the accuracy of surgical planning software for defining virtual cutting planes for hepatic resection. The primary aim was to correlate the volume of the virtual remnant and the volume of the actual remnant, where the postoperative volume is computed directly from postoperative imaging scans as a true measure of accuracy; the secondary aim was to assess early liver regeneration patterns in the early postoperative period.

METHODS

The data reported in this study were collected during a prospective clinical trial (ClinicalTrials.gov ID: NCT00782886) sponsored by Pathfinder Therapeutics Inc., supported by a grant from the Small Business Innovative Research fund provided by NIH/National Cancer Institute, titled "Evaluation of Image-Guided Liver Surgical System for Resection of Liver Cancer," and conducted at 3 treatment centers: University of Florida, Gainesville, Memorial Sloan-Kettering Cancer Center (MSKCC), and University of Pittsburgh Medical Center (UPMC) from June 2008 through June 2010. This was a clinical trial aimed at assessing the utility and safety (phase II equivalent) of the Pathfinder intraoperative image guidance system. Institutional Review Board authorization was obtained from the participating institutions before the study. Demographic, laboratory, histopathologic, operative, perioperative, and survival data were collected prospectively and analyzed retrospectively. Patients received standard contrast-enhanced preoperative MRI or CT scans, as is standard practice at the participating institutions. As part of the IRB protocol, patients received a postoperative CT scan in the immediate days after surgery. Complications were graded according to the Common Toxicity Criteria from the National Cancer Institute.

Patient selection

Candidates for resection of malignant or benign tumors with measurable disease on preoperative imaging and surgical treatment requiring removal of at least 1 anatomical segment were selected for the study. Patients with cirrhosis of the liver classified as Child-Pugh score B or C, thrombocytopenia, or renal insufficiency (defined as creatinine >2.5 mg/dL), were excluded from consideration. The preoperative evaluation, intraoperative management, and conduct of the operation at the 3 centers have been described previously.[16-18]

Preoperative planning software

Scout Liver (Pathfinder Therapeutics) is commercially available preoperative planning software that provides 3-dimensional visualization and measurement of structures of interest in the liver using CT and MRI imaging studies. The software allows the user to manually or semi-automatically segment the liver, intrahepatic vessels, and tumors. A sample Scout Liver after segmentation is depicted in Figure 1. Specific surgical strategies can be virtually defined by delineating resection lines and ablation paths. The software provides volumetric measurements of functional liver volume, remnant liver volume, and lesions as well as measurements of the planned resection. The software allows the user to query, choose, and pull scans directly from the patient records and communication system, requires 5 to 15 minutes to run and then