Traditional surgical planning of liver surgery is modified by 3D interactive quantitative surgical planning approach: a single-center experience with 305 patients

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BACKGROUND: Decision making and surgical planning are to achieve the precise balance of maximal removal of target lesion, maximal sparing of functional liver remnant volume, and minimal surgical invasiveness and therefore, crucial in liver surgery. The aim of this prospective study was to validate the accuracy and predictability of 3D interactive quantitative surgical planning approach (IQSP), and to evaluate the impact of IQSP on traditional surgical plans based on 2D images.

METHODS: A total of 305 consecutive patients undergoing hepatectomy were included in this study. Surgical plans were created by traditional 2D approach using picture archiving and communication system (PACS) and 3D approach using IQSP respectively by two groups of physicians who did not know the surgical plans of the other group. The two surgical plans were submitted to the chief surgeon for selection before operation. The specimens were weighed. The two surgical plans were compared and analyzed retrospectively based on the operation results.

RESULTS: The two surgical plans were successfully developed in all 305 patients and all the 3D IQSP surgical plans were selected as the final decision. Total 278 patients successfully underwent surgery, including 147 uncomplex hepatectomy and 131 complex hepatectomy. Twenty-seven patients were withdrawn from hepatectomy. In the uncomplex group, the two surgical plans were the same in all 147 patients and no statistically significant difference was found among 2D calculated resection volume (2D-RV), 3D IQSP calculated resection volume (IQSP-RV) and the specimen volume. In the complex group, the two surgical plans were different in 49 patients (49/131, 37.4%). According to the significance of differences, the 49 different patients were classified into three grades. No statistically significant difference was found between IQSP-RV and specimen volume. The coincidence rate of territory analysis of IQSP with operation was 92.1% (93/101) for 101 patients of anatomic hepatectomy.

CONCLUSIONS: The accuracy and predictability of 3D IQSP were validated. Compared with traditional surgical planning, 3D IQSP can provide more quantitative information of anatomic structure. With the assistance of 3D IQSP, traditional surgical plans were modified to be more radical and safe.

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KEY WORDS: precision; quantitative; surgical planning; reconstruction; hepatectomy

Introduction

To achieve the multi-objective optimization of maximizing the removal of the target lesion, maximizing the functional liver remnant and minimizing the surgical invasiveness (3M) of liver surgery, the surgical plan should be made with high certainty of precision.[1] However, traditional surgical planning, mostly based on 2D images, may not provide enough informa-

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tion surgeons required, especially for some complex hepatectomies. On the contrary, 3D reconstruction images may provide more real and intuitive information.[2-6] Between April 2010 and July 2016, we conducted this prospective study with the largest number of patients published to date to validate the accuracy and predictability of a 3D interactive quantitative surgical planning approach (IQSP), and evaluate the impact of IQSP on traditional surgical plans based on 2D images.

Methods

Study design

The study was conducted according to the principles expressed in the *Declaration of Helsinki*. The study protocol was approved by the Institutional Ethics Committees of Beijing Tsinghua Changgung Hospital and Chinese PLA General Hospital. Traditional 2D surgical plans and 3D surgical plans were made using picture archiving and communication system (PACS) and IQSP respectively by two groups of surgeons. Each group had two HPB residents of R4 and the participants were in similar expertise including CT/MRI review and operation number performed, who did not know the surgical plan of the other group. Two surgical plans were submitted to the chief surgeon for selection and decision. The accuracy of IQSP were assessed with respect to volume calculation and territory analysis for hepatic vessels, and the predictability with respect to virtual resection including the functional liver remnant volume (FLRV), transaction plane, and the integrity of inflow and outflow vasculature of remnant liver. Based on operation results, the two surgical plans were compared and graded according to the significance of differences, validating the impact of IQSP on traditional surgical plans.

Patients

Between April 2010 and July 2016, 305 consecutive patients with malignant tumors and symptomatic benign tumors (163 males, 142 females; mean age 56±7 years) who were planned to undergo hepatectomy in our institution were included. Patients undergoing operations for hilar cholangiocarcinoma and graft harvesting for living donor liver transplantation were excluded.

Imaging data acquisition

Multislice CT scans were acquired using SOMATON Sensation64 (Siemens Medical Solutions, Erlangen, Germany) with the following protocol: 120 kV, 200-220 mA, collimation of 64×0.6 mm, pitch of 0.625, reconstruction interval of 1.172 mm, slice thickness of 1.5 mm after reconstruction. Arterial and venous phase scans were acquired 20-40 seconds and 70-100 seconds, respectively, after administration of contrast agent.

Enhanced magnetic resonance imaging (MRI) scans were acquired using Signa Excite 1.5T (GE) with the following protocol: 1.25-mm thickness, no skip, repeat time of 11 milliseconds, echo time of 2 milliseconds, and flip angle of 15°. Arterial and venous phase scans were acquired 20-30 seconds and 60-70 seconds, respectively, after administration of contrast agent.

Principles of surgical planning

Surgical plans were made to determine the following aspects: (i) the target lesion and region of obligatory hepatectomy; (ii) the essential functional liver volume and the obligatory extent of liver preservation; (iii) the FLRV; (iv) the optimal procedure for hepatectomy and the optimal transection plane; (v) the vasculature to be resected and reconstructed.

Laparoscopic approach was preferred for uncomplex hepatectomy. As for most complex hepatectomies, laparotomy was preferred due to the complexity of manipulation.

Anatomic hepatectomy is preferred in cases with lesions distributed segmentally, as well as cases where removal of the involved pedicle is required. Non-anatomic resection is more appropriate for benign tumors, carcinoma *in situ*, peripheral lesions that do not involve main vessels, or patients with marginal functional liver reserve which requires more FLRV.

The resectability of lesions was determined by comprehensive review of: (1) the ratio of FLRV and standard liver volume remnant liver (FLRV/SLV), $SLV^{[7]}=706.2 \times BSA$ (body surface area, m^2)+2.4, $BSA^{[8, 9]}=W$ (weight, $kg)^{0.425} \times H$ (height, $cm)^{0.725} \times 0.007184$; (2) biological behavior of the lesions; (3) the integrity of structure and function of remnant liver.

Traditional 2D surgical planning

Traditional surgical plans were made mainly through PACS. A line indicating the resection plane was drawn according to the anatomic landmarks (hepatic veins, portal veins, and the gallbladder). The resected volume (2D-RV) and liver remnant volume (2D-LRV) were calculated through sum of areas extracted in sequential layers manually.

3D IQSP

With assistance from an IQSP system (IQQA-Liver, EDDA Technology, USA), quantitative 3D surgical plans were created interactively in real-time in the following fashion: Step 1, analyze the liver by quantification of