Evaluation of Resection Proposals for Liver Surgery Planning

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Abstract:

Modern software for surgery planning allows for definition of virtual resections within the liver. Thus, surgeons can simulate different resection strategies and assess the associated surgical risk preoperatively. Until now, it was impossible to measure the quality of different resection plans objectively. The choice for the optimal resection strategy was based on subjective judgment acquired by other examinations and subsequent risk analyses. We present a fast method for quality assessment of resection proposals with respect to surgical risk factors such as safety margin, remnant volume, remnant perfusion, surface curvature, and resection area. Our new method has been integrated into planning software used in the daily routine. The results from a preliminary user study confirm that the interactive quality feedback is beneficial for precise liver surgery planning.

Keywords: Liver Surgery, Resection Planning, Deformable Cutting Plane, Quality Assurance

1 Purpose

The definition of a virtual resection is an important step in liver surgery planning. Besides the necessity of preserving enough functional liver parenchyma, depending on liver disease and supply and drainage of the remnant, the distance of the resection surface to the tumor is a major concern. While ensuring these requirements, the resection surface needs to be smooth and ideally as small as possible to facilitate the intervention for the surgeon.

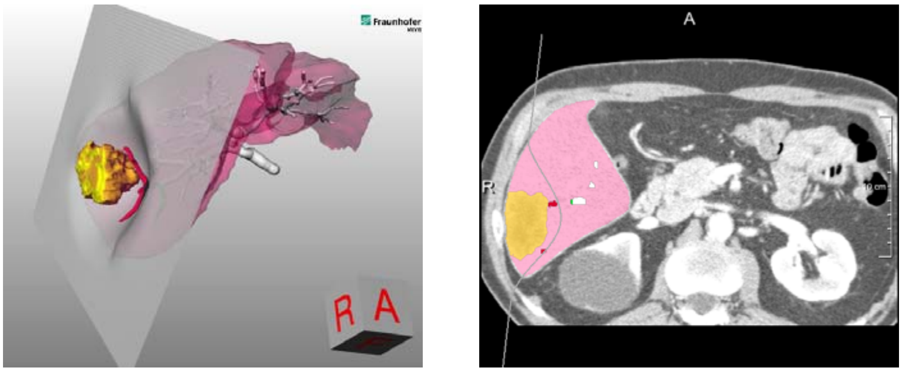

Fig. 1: Resection proposal for a non anatomical resection of a tumor in the liver. Segmented anatomical structures and the deformable cutting plane are displayed in 3D (left) and 2D (right).

It is a complex task for a user to evaluate those factors simultaneously during planning and to choose the corresponding best resection strategy. To this end, we present a method for interactive computation of quality properties and for transformation of these properties into a single quality measure that can be used to compare different resection proposals.

2 Methods

Based on the defined resection surface and on segmentation results of liver, tumors, and vessels (portal vein, hepatic vein), a resection score $G \in [0, 1]$ is calculated. Thereby, following risk factors $R_i \in [0, 1]$ influence the score:

1. Remnant volume in *ml*
2. Safety margin around tumors in *mm*
3. Supplied volume of the remnant liver in *%*
4. Drained volume of the remnant liver in *%*
5. Completely perfused remnant liver in *%*
6. Resection area in *cm²*
7. Curvature of resection surface in *degree*

2.1 Evaluation of Resection Proposals

The quantitative results of each risk factor R_i are mapped onto the interval [0, 1] and weighted either linearly or sigmoidally with the factor w_i. The overall score G is the weighted average of the individual scores R_i and computed as followed:

$$G(\vec{R}, \vec{w}) = \begin{cases} 0 & \text{if } \sum_{i=0}^{6} w_i = 0 \\ 0 & \text{if } v_{Rem} < v_{Min} \\ 0 & \text{if } dst < d_{Min} \\ \frac{\sum_{i=0}^{6} w_i R_i}{\sum_{i=0}^{6} w_i} & \text{else} \end{cases}$$

where v_{Rem} represents the amount of remnant liver volume, and *dst* the minimal distance between resection surface and tumors. In this context, v_{Min} *and* d_{Min} are boundary values that can be defined by the user. In order to understand the composition of the proposed evaluation function, we describe the calculated risk factors R_i in detail:

Remnant Volume Because the amount of sufficient remnant volume depends on patient condition and pre-existing impairment of the liver, empirical values are used to determine a minimal volume necessary to avoid postoperative organ failure. As stated in the literature, the remnant volume has to be at least 20% of the total estimated liver volume, 30%–60% if the liver is injured by chemotherapy, steatosis, or hepatitis, or even 40%–70% in the presence of cirrhosis [2]. The maximal achievable remnant volume results in the total liver volume excluding the volume of tumor and the associated minimal safety margin. The interval between the minimal volume and the theoretically achievable volume in *mm* is mapped either linearly or sigmoidally onto the interval of [0, 1].

Safety Margin The safety margins around tumors are the second major criterion used to evaluate resection proposals. On the one hand, it is important to completely remove all cancer cells around the visible tumor on CT data, and such a large margin without other risks facilitates the operation for the surgeon. On the other hand, wide safety margins result in less remnant volume and imply more potential intersections with intrahepatic vessels. Therefore the evaluation is performed either linearly or sigmoidally within an interval of a few millimeters, depending on tumor type and surgical preferences.

Supply, Drainage and Perfusion While assuring enough residual liver volume with a given resection strategy, supply and drainage may be impaired due to intersections of the resection surface with the corresponding vessel system. The remnant volume may be functionally insufficient, which has to be expressed in the evaluation of the resection plan. Ideally, a resection proposal ensures a totally perfused (totally supplied and drained) remnant volume. The percentage of supply, drainage, and perfusion are either directly taken for evaluation of these risk factors or are sigmoidally mapped onto [0, 1].

Resection Area The area of a resection surface depends on the type of resection. Local resections of large tumors usually have large areas, whereas anatomical resections, which divide the liver into two parts, could have smaller areas. However, large resection surfaces often imply more potential bleeding due to intersections with intrahepatic vessels. Resection surfaces with less area should therefore be evaluated with a higher score. To be able to compare different resection strategies, even of different patients, the evaluation is based on the relative resection area in relation to the liver surface area. A quantitative analysis of 15 cases with 31 resection proposals with different resection strategies has shown that the relative resection area is between 5% and 25%. This interval is sigmoidally and reversely mapped onto [0, 1].

Resection Curvature The shape of the resection surface is ideally smooth and planar. This is not feasible for local resections, and it becomes harder to operate when a resection surface differs greatly from planarity. To calculate a curvature score, a deformable cutting plane [1] internally consisting of triangles is used by taking the average of the maximal dihedral angles between node and face normals. The analysis of 15 cases with 31 resection proposals with different resection strategies has shown that the average resection curvature lies between 0 and 6 degrees for these cases. This interval is sigmoidally and reversely mapped onto [0, 1].

Weights $w_i \in [0, 6]$ and default values for minimal remnant volume and minimal safety margin for different tumor types were determined together with our clinical partners. Table 1 shows a comparison between the preferences for hepatocellular carcinoma and liver metastases.

Preference	Hepatocellular Carcinoma	Metastases
Minimal Safety Margin	2 mm	0 mm
Minimal Remnant Volume	50%	25%
Weights		
Remnant Volume	6	2
Safety Margin	5	4
Remnant Supply	0	0
Remnant Drainage	0	0
Remnant Perfusion	5	6
Resection Area	2	4
Resection Curvature	1	3

Table 1: Preferences and weights for oncologic resections of different tumor types. The weights for remnant supply and remnant drainage are set to zero in order to evaluate the perfusion only.

2.2 Data Structure for Fast Evaluation

To be able to compute the resection score in real time during planning, a new data structure has been developed which compactly stores the segmentations of liver, portal vein, hepatic vein, tumors, and rastered resection surface in a 3D byte array. The bits of these bytes represent flags of locally defined segmentation results and the current supply and drainage state, see figure 2. Additionally, the distance transformation of the tumor segmentation is precalculated in order to compute the safety margin. Furthermore, vessel graph representations and assignment maps of the portal vein and hepatic vein are used to calculate supplied and drained territories after intersection with the resection surface. Once this data structure has been initialized, memory storage of the original segmentation results and vessel assignment maps can be released. The mean computation time for the entire evaluation function is approximately 1 second, measured on Intel Core2 Duo @3,16 GHz, 8 GB Memory, Windows 7 64 Bit.

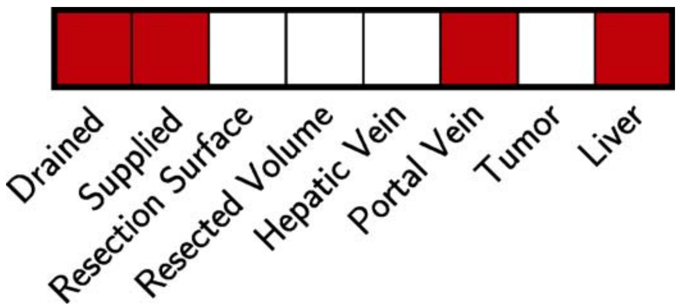

Fig. 2: Schematic representation of a byte-voxel of the new data structure. This example shows a liver voxel with portal vein vessel segmented in a territory which is both supplied and drained.

3 Results

The new methods are available in an add-on for the *MeVis LiverAnalyzer* planning software [3] and integrate smoothly into a preoperative planning workflow. In addition, we evaluated the methods in a user study with two radiological technicians. The results of conventionally determined resection proposals were compared with resection proposals defined using the new approach by evaluating the conventionally planned results “offline”. The evaluation confirms that resection proposals show a better quality when considering the proposed evaluation function. In particular, safety margins around tumors were more accurately defined. However, due to the presentation of additional information, users took more time (approximately 5 minutes) when defining a virtual resection surface.

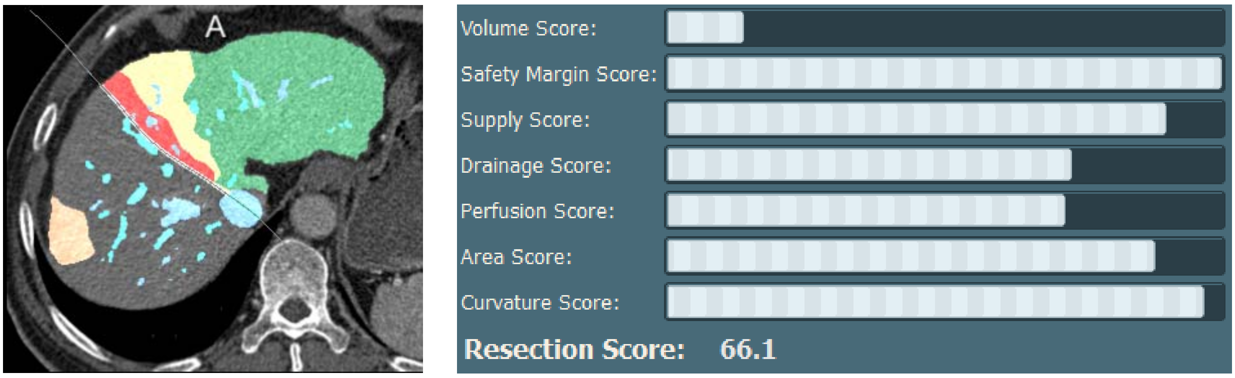

Fig 3: Risk overlay (left) of impaired remnant projected onto the CT images and evaluation results (right) of the seven risk factors.

4 Discussion and Future Work

We have introduced a method for the quantitative evaluation of resection proposals in liver surgery planning. The new method shows additional information which is not directly visible in the radiological data. It enhances the approved method for virtual resection planning by providing interactive feedback during the definition of the resection surface. Thus, it has the potential to improve the accuracy and quality of preoperative resection plans. To prove the clinical benefit of the new methods, a clinical evaluation is desirable. Therefore, a quantitative user study with a large, representative selection of oncologic cases is ongoing. However, in order to realize the virtually defined cutting path a navigation system with high accuracy is required.

The concept of resection evaluation was designed initially for precise planning in liver surgery. Application to other surgical fields, such as neurosurgery, shows great promise and could be a part of our future research.

5 References

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