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Towards Automatic Generation of Resection Surfaces for Liver Surgery Planning

Purpose

Recent planning software for liver surgery provides valuable tools to evaluate different resection strategies. Although most processing steps of the data analysis are already automated, the actual resection planning is still done completely manually, in that the user defines the orientation and shape of the resection surface by drawing and dragging. However, such interaction is prone to error and consumes time in the clinical routine. The resulting resection surface is not standardized and may vary depending on the experience and endurance of the user. Furthermore, additional tumors that were not detected in the preoperative image data are quite often found during the intervention using intraoperative ultrasound. Due to such findings, preoperatively prepared resection plans have to be updated or completely revised during the intervention. Thus, an automated generation of resection plans would be of great benefit.

Methods

In this work, we present a new method for the automatic generation of resection surfaces. Our method computes an initial deformable mesh that needs only slight modifications by a user to achieve the final resection surface. A prior analysis of CT or MR images which provides segmentation masks of tumors, hepatic vessels, and the liver surface builds the basis. Our approach considers common surgical resection techniques, i.e., anatomic and non-anatomic resection surfaces.

For anatomical resections (e.g. hemi hepatectomy), the boundaries of the portal venous territories guide the resection proposal (Fig. 1 a-b). A deformable cutting plane is aligned to these boundaries using a principal component analysis to derive surface orientation and extent. However, since main branches of the hepatic vein are often located along anatomical resection surfaces, additional vessels, not directly affected by the tumor, might be cut. To avoid such cascading effects, the resection proposal calculated on the basis of the portal vein territories has to be adjusted appropriately.

In the case of a non-anatomical resection (e.g. wedge resection), the affected liver tissue is identified by an evaluation of different safety margins around tumors. Selecting an appropriate safety margin width, an initial resection volume is calculated (Fig. 2). In order to provide an access path to the tumor, a deformable cutting plane is placed outside of the liver and deformed using a displacement map based on the initial resection volume to generate a reasonable and transferable convex resection shape (Fig. 1 c-d).

Results and Discussion

The method was embedded in a software assistant for liver surgery planning and was evaluated in a retrospective quantitative study with 55 oncologic resections that were manually planned by medical experts. Due to the enormous variability of such resections, the results were evaluated pair-wise regarding similarity measures (such as the Dice coefficient), surface curvature, and maximal distances between surfaces. As expected, the outcome of the algorithm was not exactly the same as the manually planned resections. However, our process generated reasonable resection proposals for the selected cases. The automatism does not necessarily aim for an exact reproduction of the manual resection surface as planned by the medical experts, but to provide an automatism which computationally derives structures to be removed. To our knowledge, the presented method is the first approach to automate the generation of resection proposals for liver surgery.

Conclusion

Currently, it is an ambitious task to automatically create feasible resection proposals and it remains unclear whether this is even possible for all cases. However, in simple anatomical situation, we were able to achieve reasonable results, as demonstrated in this work. In complex anatomical situations, the automated resection proposal was found to be a good starting point for the final adjustment.

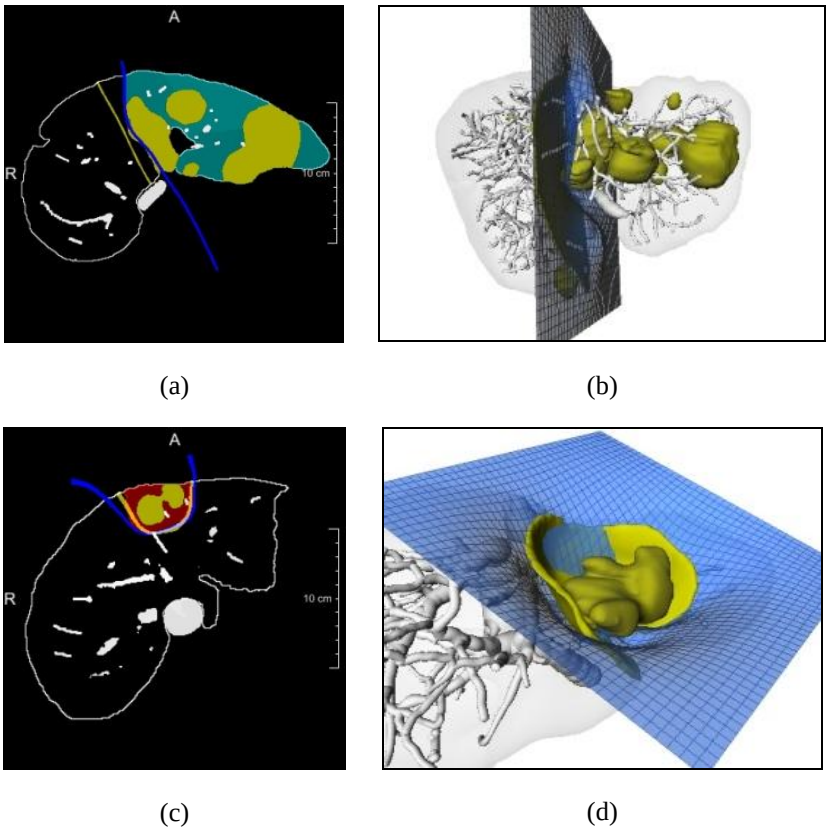

Fig. 1. Automatically generated resection proposals in 2D and 3D for a anatomical resection (a, b) and a non-anatomical resection (c, d): The generated resection surfaces (blue) coincide well with resection surfaces generated by medical experts (yellow).

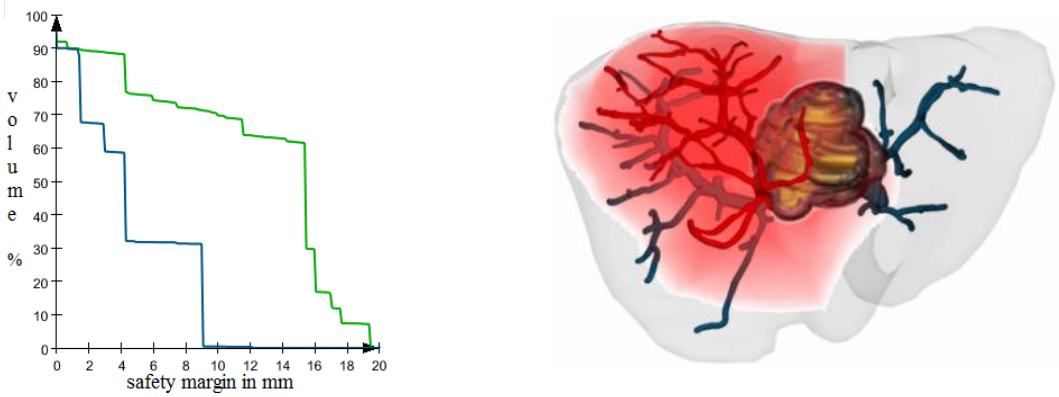

Fig. 2. (a) Margin-Volume function for the portal vein (blue curve) and the hepatic vein (green curve) showing the relation between the remnant volume (vertical axis), and the width of the safety margin (horizontal axis) around a tumor. The discontinuities in Margin-Volume function correspond to vessel branches that are potentially transected. (b) Visualization of liver tissue that is not supplied (red) by the portal vein when a margin of 3 mm is applied.