Impact of Model-based Risk Analyses for Liver Surgery Planning

C. Hansen[1], S.Zidowitz[1], B. Preim[2], K. J. Oldhafer[3], H. K. Hahn[1].

[1] Fraunhofer MEVIS, Institute for Medical Image Computing, Bremen, Germany
[2] Otto-von-Guericke Universität Magdeburg, Magdeburg, Germany
[3] Asklepios Hospital Barmbek, Hamburg, Germany

Contact: Christian.Hansen@mevis.fraunhofer.de

Abstract:

The success of an oncological resection of the liver depends, among other factors, on the width of safety margins around tumors. Therefore, methods for determination of optimal safety margin are described in literature. These methods visualize the surgical risk for a specific saftey margin based on a geometric model of the liver.

To prove whether and how these methods facilitate the process of liver surgery planning, an explorative user study with 10 liver experts was conducted in this work. The purpose was to compare and analyze their decision making. The results of the study show that model-based risk analysis enhances the awareness of surgical risk in the planning stage. Participants preferred smaller resection volumes and agreed more on the safety margins width in case the risk analysis was available. In addition, time to complete the planning task and confidence of participants was not increased when using the risk analysis.

This work shows that the applied model-based risk analysis may influence important planning decisions in liver surgery. It lays a basis for further clinical evaluations and points out important fields for future research.

Keywords: Computer-assisted Planning, Visualization, Liver Surgery, Evaluation

1 Purpose

The determination of optimal safety margin widths around liver tumors is a challenging surgical task. Type, number, volume, and location of tumors and their relation to vessels are all important factors when deciding whether a R0 resection can be achieved. Thereby, surgeons have to find a compromise between the safety margin width and the estimated postoperative liver volume.

To this end, methods for model-based risk analysis in liver surgery are described [1-4]. Using a recent aproach by our group [2], the dependency of vascular territories from safety margins around tumors can be explored. Robustness and sensitivity of vascular risk in the liver is visualized within a volume-margin function (Fig. 1, upper right). The volume-margin function visualizes the affected liver volume as a function of the saftey margins width. In addition, interactive 3D renderings of the liver that illustrate the impaired liver volume for the portal vein (Fig. 1, upper left), and the hepatic vein (Fig. 1, upper middle) can be provided.

To prove whether and how model-based risk analyses facilitate the process of liver surgery planning, an explorative user study was conducted. In our previous work [2], this aspect was not studied in detail. The purpose of the study presented in this paper was to compare and analyze the decision making of liver surgeons and radiologic technicians.

2 Method

To generate evaluable data during the experiments, meaningful reference criteria need to be defined. These criteria should provide the basis for an objective comparison between the proposed method and a reference system. Three reference criteria were derived from questions that typically arise during the planning of surgical liver interventions:

(C1) Resectability
(C2) Resection strategy
(C3) Safety margins widths around tumors

These criteria are based on subjective assessments by study participants. In addition, reference criteria which can be derived from this decision-making process are defined:

(C4) Total time to analyze a case

(C5) Amount of user interaction per case
(C6) Degree of subjective confidence in decision-making

Experiment Design

The study consisted of two separate experiments, called experiment A and experiment B. Each participant completed both experiments.

In experiment A, a reference system was presented. The reference system consists of a conventional 2D/3D viewer application for planning data (cf. Fig. 1a). While the 2D viewer visualizes the radiologic slice data, the 3D viewer visualizes the 3D models of vascular structures (hepatic vein, portal vein), the liver surface, and tumors. In addition, the application provides measurement tools for the assessment of distances within the dataset.

In experiment B, the utilized software application contained all functionalities that were included in the reference system. In addition, a volume-margin function of the dataset was visualized together with an interactive 3D visualization of vessels at risk and territories at risk (cf. Fig. 2b).

In each experiment, participants were asked to analyze six CT datasets of the liver. The same six dataset were used in each experiment. For each dataset, participants had to perform specific planning tasks by using the software application. These planning tasks consisted of:

- Determination of a virtual resection surface
- Selection of critical vessel structures which should be preserved
- Selection of potential areas of impaired inflow and outflow

In addition, participants completed a questionnaire for each dataset. The questionnaire directly addresses the comparison criteria (C1-C3) defined above. In the header of each questionnaire, a report on diagnostic findings for the dataset was given and the desired postoperative liver volume was specified (> 35%).

Each experiment was conducted as follows. First, participants were informed that the experiment takes between 60 and 90 minutes and that the time is measured during the experiment. Second, the software application was presented and its graphical user interface was explained. Third, a training dataset was loaded and participants conducted the planning tasks for this dataset and filled out a questionnaire. The test supervisor ensured that all questions and planning tasks were understood. Finally, five test datasets were loaded in random order. Participants were informed that the experiment starts and that time is measured from now on. Analogous to the training phase, participants performed surgical planning tasks and filled out a questionnaire for each dataset. Verbal comments were transcribed during the experiment.

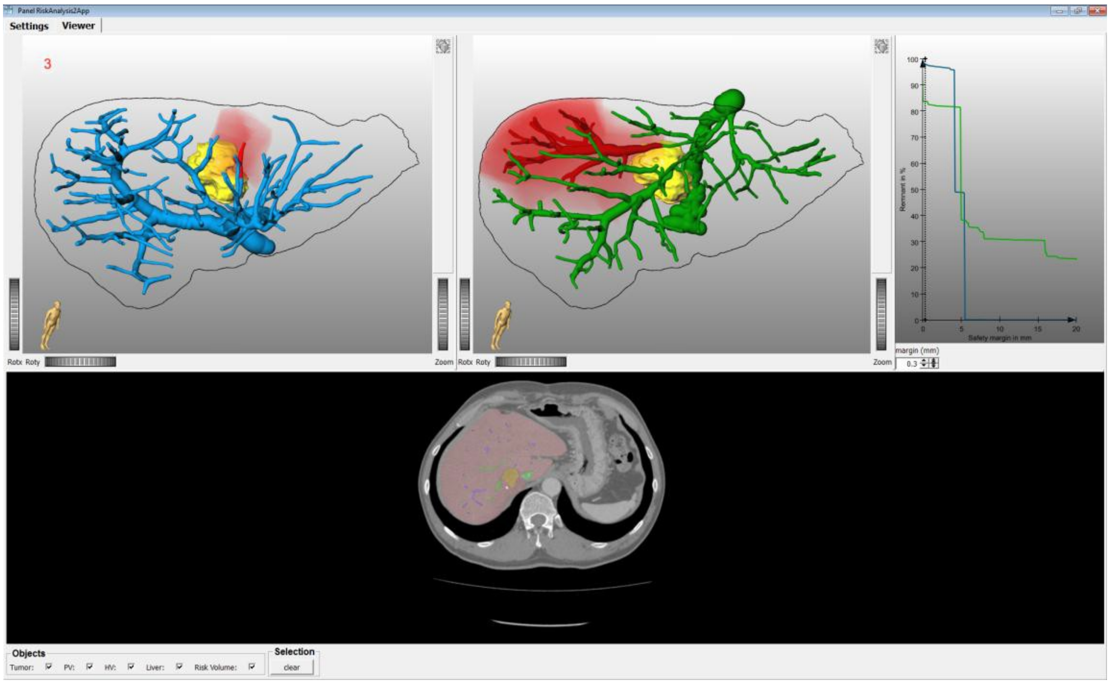

Fig 1: Screenshot of the software application used in experiment B. The graphical user interface is identical to experiment A, except that the risk analysis is provided here. A volume-margin function [2] is presented in the upper right viewport, territories at risk for the portal vein in the upper left, and for the hepatic vein in the upper middle viewport. The radiologic data and associated overlays of the 3D models can be accessed in the lower viewport.

The experiments were performed in the context of two clinical workshops at Asklepios Clinic Barmbek, Hamburg, Germany. Because not all surgeons could take part at both workshops, several separate meetings took place. The distance between experiment A and B was always at least 3 weeks in order to minimize memory effects.

Medical Datasets

The case database consisted of six abdominal CT datasets (1 training dataset, 5 test datasets). For each dataset, 3D models of the liver, hepatic vein, portal vein, and intrahepatic tumors were generated. The test datasets were selected according to the following criteria:

- Presence of colorectal liver cancer
- Solitary metastases that are located adjacent to mayor hepatic vessels
- No presence of cirrhosis

Participants

Medical knowledge and experience in liver surgery planning are necessary to perform the planning tasks and to give meaningful answers in the questionnaire. For that reason, the subject pool consisted of 10 liver experts (3 females, 7 males), including 4 chief physicians, 1 senior physicians, 2 assistant physicians, 3 radiology technicians. The mean age of the participants was 41.45 years (± 4.7). The mean number of years of surgical experience were 15.6 (±5.3), excluding the radiology technicians.

3 Results

Comparison of given assessments concerning patient (C1) resectability revealed that participants showed better agreement of answers in experiment B. In addition, the results show that participant's decisions were much more cautious and less optimistic when using the risk analysis.

The analysis of changes in the resection strategy (C2) revealed that subjects changed their resection strategy in many cases. This is unsurprising, because it can be expected that when repeating experiment A (or B) several times with the same participants, the preferred resection strategy will not be constant (test-retest variability). However, the changes observed in this study follow a clear trend towards the choice of smaller resection volumes in case the model-based risk analysis is available. This supports the above statement that the proposed methods enhance the awareness of surgical risk.

The analysis of selected safety margins widths (C3) showed that the variation of values was lower for all cases in experiment B. Thus, subjects agree more when the safety margin is chosen with the proposed risk analysis (experiment B) than with the reference system (experiment A). A selected safety margin width depends on the chosen resection strategy. Thus, the measured trend to choose smaller resection volumes in experiment B seems to have an influence on the width of safety margins, or vice versa.

The comparison of times (C4) taken to complete the test tasks revealed that there are no significant differences between experiments A and B. However, the way surgeons used the provided 2D/3D visualization techniques was different in each experiment. In experiment A, the CT slices were more often accessed than in experiment B. The numbers are many times higher in experiment A. An analysis of user interaction (C5) during the experiments also showed that interaction with the 2D slice data is required less when the risk analysis is extensively used.

The questionnaire asked participants to rank their confidence (C6) in decision-making on an ordinal scale from 1 to 4 (1 = very sure, 2 sure, 3 = less sure, 4 = not sure). An analysis of the data revealed that there exist no significant differences between experiment A and B. However, the mean values indicate that participants felt more confidence in experiment A. An interesting observation in this context was that several participants mentioned that it is even more difficult to make a final decision when considering the additional information provided by the risk analysis. Two surgeons mentioned that they selected “less sure” or “not sure” in experiment B because they would prefer to discuss the resection strategy with colleagues before making a final decision. Such verbal comments were not made in experiment A. The results of the user study can be summarized as follows:

- The applied model-based risk analysis enhances the awareness of surgical risk in the planning stage (assessment of resectability, determination of resection strategy)
- Subjects prefer smaller resection volumes in case the risk analysis is available.
- Subjects agree more on the safety margins width in case the risk analysis is utilized.
- Subjects do not take more time when analyzing a dataset using the risk analysis. In this context, 2D slices were less accessed in case the risk analyses were available.
- Confidence in decision-making is not higher when using the risk analyses.

4 Discussion

Previous studies in the field of liver surgery planning evaluated only the impact of 3D visualization [5] and virtual resection planning [6]. Thereby, the planning data was always evaluated against a presentation of 2D CT images. The study performed in this work investigated the usefulness of model-based risk analysis for liver surgery planning. The results of the study show that the proposed risk analysis may influence important planning decisions for liver surgery.

An interesting result of the study is that confidence in decision-making was not higher when using the risk analysis. The mean confidence values are even higher without the risk analysis. There are several possible explanations for this result. First, all participants were quite familiar with the 3D planning models and the exploration of 2D slice data available in experiment A. Thus, the level of trust in the new risk analyses was probably lower than in the established 2D/3D exploration techniques. This might have had an effect on the level of confidence. It is expected that the level of confidence will increase after subjects are more familiar with the approach. Second, the additional information in experiment B enhanced the awareness of surgical risk and could explain why participants rated this as less confident. Thus, the subjective confidence in decision-making might correlate with risk awareness of subjects.

The mean time to complete the planning tasks was not significantly lower when using the risk analysis. It would be interesting to measure if this were also true if participants received more training. Another reason for this could be the increase in risk awareness that opened up new questions during the planning process. Thus, additional time was required. It is also assumed that the high difficulty of the selected cases influenced the confidence of participants and the measured time.

The methods were evaluated under controlled conditions within two separate experiments. Because experiment A always took place before experiment B, a potential bias in favor of experiment B in terms of time was introduced. Thus, the results should be interpreted by taking these circumstances into account. For the future, it would be desirable to prove the benefit of the proposed risk analysis by evaluating them in clinical routine. This would require a clinical study with a randomized decision regarding the utilization of the results of the risk analysis and the subsequent evaluation of clinical criteria, such as complication rate, tumor recurrence, and blood loss [7]. In addition, evaluation criteria concerning the surgical decision making, as addressed in this chapter, could be utilized. In this context, factors, such as the anamnesis of the patient, degree of liver disease, experience of the surgeon, and surgical technique need to be carefully considered [7]. In addition, such evaluation study could shed light on the transfer of surgical plans to the actual patient. To achieve this, the preoperative made decisions and the final preoperative resection plan could be compared with the intraoperatively performed resection surface. Therefore, the performed resection needs to be measured intraoperatively, e.g., by using a surgical navigation system, or acquired using postoperative imaging.

In conclusion, this work contributes to computer-assisted liver surgery planning. It lays a basis for further developments and evaluations in the context of model-based risk analyses and points out promising fields for further research.

5 References

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