Intraoperative Adaptation of Preoperative Risk Analyses for Oncologic Liver Surgery using Navigated 2D Ultrasound

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Abstract:

Preoperative risk analyses for oncologic liver interventions have only a limited value when new tumour findings are made during operation. We propose a new method that allows an intraoperative risk analysis adaptation by merging newly detected tumors with a preoperative risk analysis. To determine the exact positions and sizes of these tumors we make use of an ultrasound-based navigation system. For the first time, we provide surgeons with an intraoperational tool for risk analyses adaptation that can easily be integrated into a surgical workflow.

Keywords: liver surgery, risk analysis, ultrasound, intraoperative imaging

1. Purpose

With recent planning software for oncological interventions, risk analyses based on the individual liver anatomy can be carried out preoperatively. Based upon security margins around each tumor, disturbances of blood supply and drainage within the remaining liver parenchyma can be computed, quantified and visualized. With regard to complex oncological resections, a computer-assisted risk analysis is important for precise and safe liver surgery [1].

However, additional tumors within the liver are frequently detected during oncological interventions using intraoperative ultrasound [2, 3]. These tumors are not visible in radiological data and their existence may change the resection strategy. In such cases, an intraoperational tool for automatic risk analysis adaptation would assist the surgeons in optimizing the resection strategy.

We propose a new application, the *Intraoperative Planning Assistant*, which allows a risk analysis adaptation by merging intraoperatively detected tumors with a preoperative risk analysis. Unlike previous approaches for risk analysis adaptation [4], we make use of an ultrasound-based navigation system [5, 6] to determine the exact positions and sizes of newly found tumors. Based on an XML-based communication protocol, the *Intraoperative Planning Assistant* is able to exchange crucial data with the navigation system during an intervention.

2 Methods

The preoperative planning results are based on contrast enhanced CT or MR scans acquired with standard examination protocols. For the risk analysis relevant intrahepatic structures are segmented semi-automatically and affected vascular branches, as well as affected liver territories, are computed and visualized [7]. This service is provided by the *Intraoperative Planning Assistant* which runs on a workstation outside of the sterile area of an OR. The preoperative planning results can be accessed from a navigation system by sending an XML-request to the *Intraoperative Planning Assistant* (Fig 1). The

Intraoperative Planning Assistant responds by sending a message including the location of relevant data files, providing quantitative information (XML) and geometric objects (VRML), which can be downloaded via FTP. That data exchange allows a simultaneous visualization of planning results and navigated 2D-ultrasound at the navigation display, which is located in front of the situs.

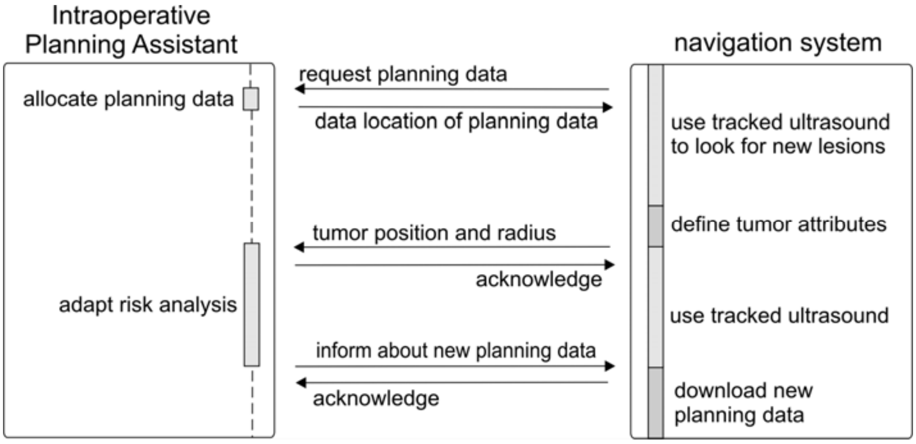

Fig 1: Exchange protocol, defined between *Intraoperative Planning Assistant* and navigation system.

If additional tumors are found during surgery, tumor size and position are directly defined at the 2D-ultrasound image on the navigation display. For simplicity, tumors are assumed to be approximately spherical in shape and it is therefore sufficient to draw a circle around the tumor. After tumor attributes have been determined, the navigation system sends a request for a planning update, containing the new tumor radius and position, to the *Intraoperative Planning Assistant*. In case the request is accepted, the tumor is added to the planning model and a risk analysis adaptation is performed by the *Intraoperative Planning Assistant*. To create a new risk analysis, an Euclidean Distance Transformation is applied to calculate the distances between vessels and tumors. Affected vessels are identified and relabeled depending on the predefined security margins (Fig 2). Furthermore, a precalculated Voronoi Tessellation with respect to the vasculature is exploited to approximate the volume of parenchyma supplied or drained by the affected vessels (Fig 3). After the computation has finished, the *Intraoperative Planning Assistant* sends a response to the navigation system and the planning update is immediately available on the navigation display. Using a multi-scale approach for the underlying volume data, our algorithm for risk analysis adaptation can choose a trade off between accuracy and computation time.

To calculate the exact position of a newly found tumor, a registration between the intraoperative ultrasound images and the preoperative planning data is required. We implemented a registration method that is robust, executable in real-time and interactively adaptable. It requires the surgeons to define a small set of corresponding markers in both the preoperative radiological data and the intraoperative ultrasound images using anatomic landmarks like vessel branchings. By minimizing total squared distances of the corresponding markers, we compute an affine transformation and apply it to the preoperative data.

3. Results and Future Work

Preliminary evaluations in the OR confirm that in case of newly discovered tumors an adaptation of a preoperative risk analysis is a beneficial support for precise liver surgery (Fig 4). Our application, in combination with an ultrasound-based navigation system, offers crucial decision support and is easy to use. Using an XML-based communication protocol, the provided service can be utilized by other systems as well. To improve the alignment of intraoperative ultrasound images to preoperative data, the landmark-based registration will be augmented by an intensity-based elastic registration. For the near future we plan to evaluate our system under realistic conditions during oncological interventions with a focus on registration accuracy.

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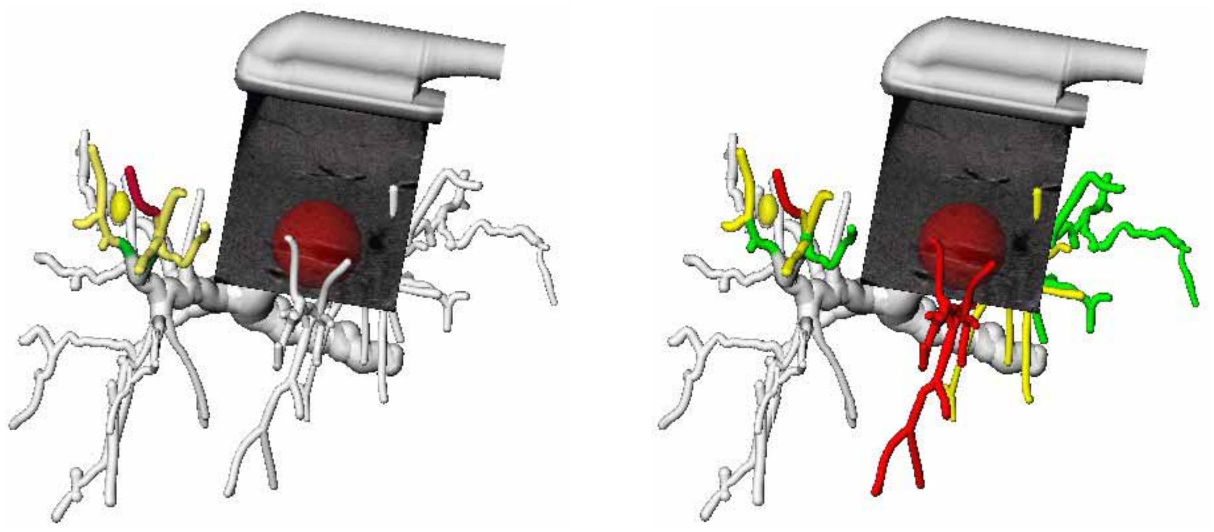
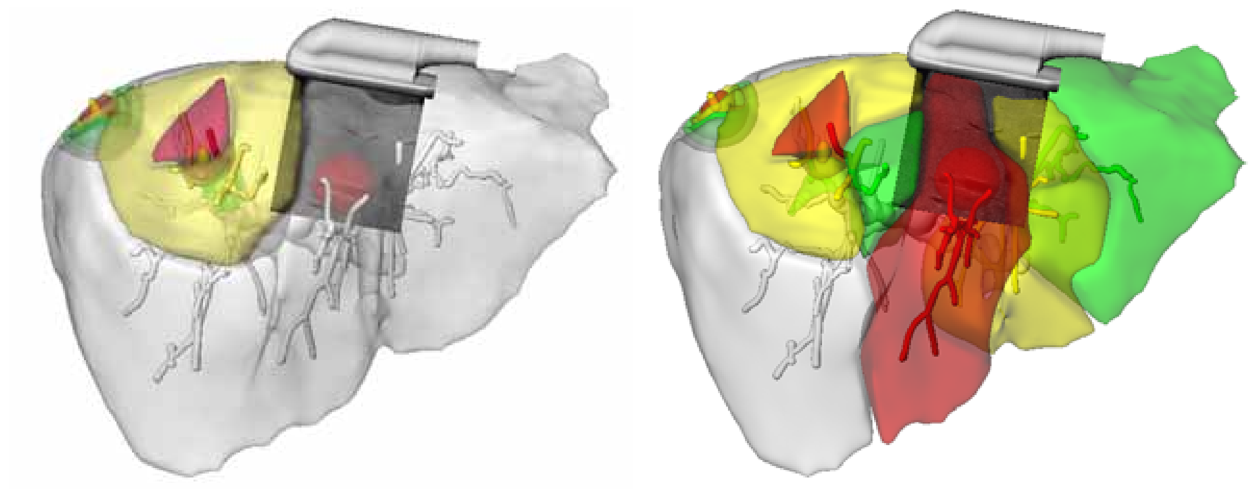


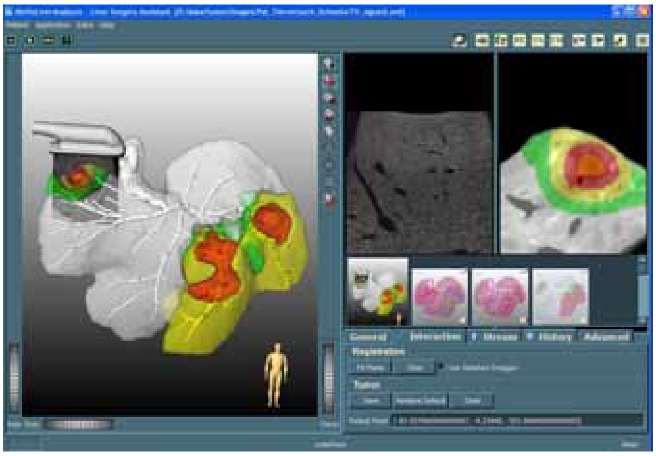
(a) (b)

Fig. 2: (a) Preoperative risk analysis for a portal vein. Three standard security margins around the tumors are chosen and displayed in red (5mm), yellow (10mm) and green (15mm). The red sphere on the ultrasound plane shows an intraoperatively detected tumor before adapting the risk analysis. (b) Adapted risk analysis including relabeled vessels, visualizing the risk for the new tumor.



(a) (b)

Fig. 3: (a) Preoperative parenchyma at risk that is supplied by the affected vessels. (b) Adapted risk analysis showing the updated parenchyma at risk.



(a) (b)

Fig. 4: (a) *Intraoperative Planning Assistant* showing the risk analysis for a pig's liver with artificial tumors before applying a risk analysis adaptation. (b) Preliminary evaluations in the OR using an ultrasound-based navigation system and the *Intraoperative Planning Assistant* for laparoscopic liver surgery.

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