Planning of Anatomical Resections and In-situ Ablations in Oncologic Liver Surgery

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Abstract

We describe a software system that helps both to determine anatomically correct and surgically realizable resection territories and to plan minimally invasive interventions for cases, that are impracticable for surgery.

Keywords: Liver surgery planning, minimally invasive, anatomical resections

1. Introduction

In oncologic liver surgery, preoperative planning requires detailed knowledge about the patient's anatomy. The spatial relations between pathological and vital structures are essential for estimating the risks of minimally invasive and surgical treatment.

For conventional surgery, a computer-based planning system is primarily used to find the optimal resection strategy. The resection has to fully enclose the tumors to be removed, whereas main branches of the vascular systems must not be destroyed to guarantee that the remaining functional part of the liver is sufficient for the patient's survival. Resection strategies are mostly based upon the anatomical scheme of the liver introduced by Couinaud. Evaluating the suitability of a planned resection requires the determination of those parts of the vascular system that would be destroyed by the planned resection and determining both the dependent vascular territories and their volumes.

If a surgical resection proves impossible as a result of either a tumor's location, its size or the patient's constitution, the destruction of a tumor by minimally invasive thermal interventions, such as laser-induced thermotherapy (LITT) or radio-frequency ablation (RF), often is a viable alternative. However, profound planning is even more important for minimally invasive therapies than in conventional surgery. On the one hand, vascular territories have to be respected as well, on the other hand, there is a lack of visual control of the ongoing therapy due to limitations of intraoperative imaging. Moreover, minimally invasive strategies require planning of the instruments' trajectories to ensure that major vascular branches are not violated.

2. Related work

We previously presented a planning system [1] that proposes resection areas for oncologic surgery. This prior version consists of a segmention of the intrahepatic structures and a hierarchical analysis of the vascular systems [2]. Based on this analysis, the resection proposal, namely that territory which is affected if only the tumor including a security margin is removed, is determined automatically. Other groups presented planning software that follows the same paradigm [3]. However, while our systems takes both portal and hepatic veins into consideration, their resection proposals are based on the portal vein, which makes the results less suitable for clinical practice.

Considering planning of minimally invasive therapies to our knowledge no existing system takes the cooling effect of the patient's individual intrahepatic vessels into account. Butz et al developed a system which allows for adequate planning of applicator placement, but instead of simulating the heating or cooling on an individual basis, they determine the destroyed tissue by merely transfering standardized shapes of lesions won from previsous interventions into the new planning dataset [4]. The LITCIT (Laser-Induced Temperature Calculation In Tissue) developed by Roggan et al [5] at the LMTB (Laser- und Medizintechnik Berlin) and the system published by Puccini et al [6] simulate each intervention individually, but these systems do not specifically define intrahepatic vascular systems and, thus, neglect their cooling.

3. Planning of resection territories

3.1 Problems with automatic resection proposals

Experiences gathered in clinical practice show that the proposals calculated by our previously mentioned system help to facilitate planning of anatomical resections, but occasionally have significant drawbacks: In cases of dorsally situated tumors they sometimes are not realizable, as no appropriate access to the resection area can be found (ca. 5% of all cases). Moreover, the proposals can become very complex in shape, leading to a large surgical surface that physicians generally try to avoid to restrict blood loss.

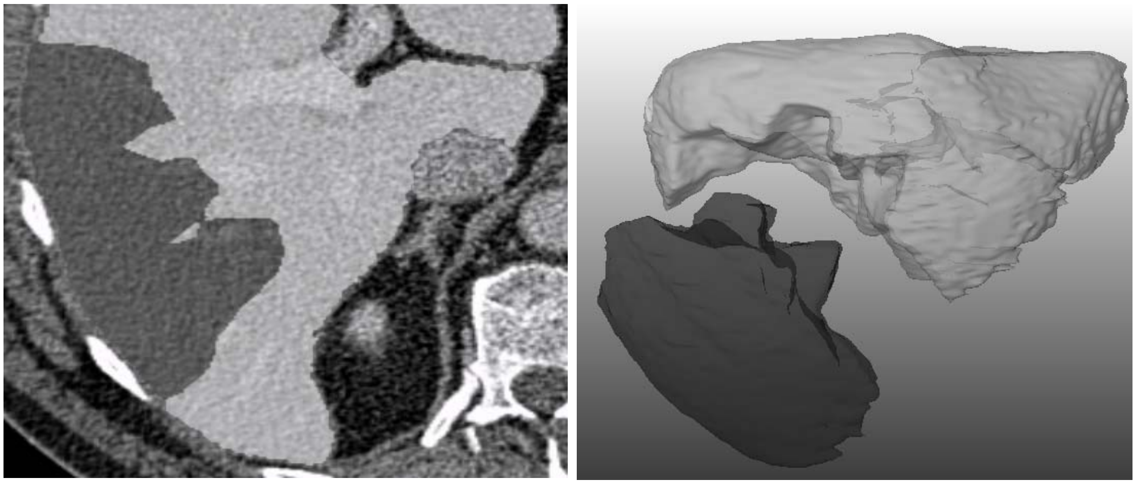

Fig. 1: Automatically computed resection proposals sometimes are very complex in shape and, thus, not surgically realizable.

3.2 Manual resections

To overcome these drawbacks we have improved our system by the possibility to manually define the resection area based upon the automatically generated one. Still, the physician is shown the territory's borders in both 2D and 3D; however, this territory is no longer regarded as a resection area, but rather serves as an orientation for the physician to manually define the desired resection territory, which can be easily drawn either as a straight, curved or freehand line into the scene. The drawing has to be carried out for very few slices only as the lines are interpolated or, if only one line has been specified, propagated throughout the complete dataset. With the latter approach, the resection shape is extruded along the whole dataset. By converting the lines into Bezier-curves it is ensured that both interpolated and original borders can be easily edited and locally modified.

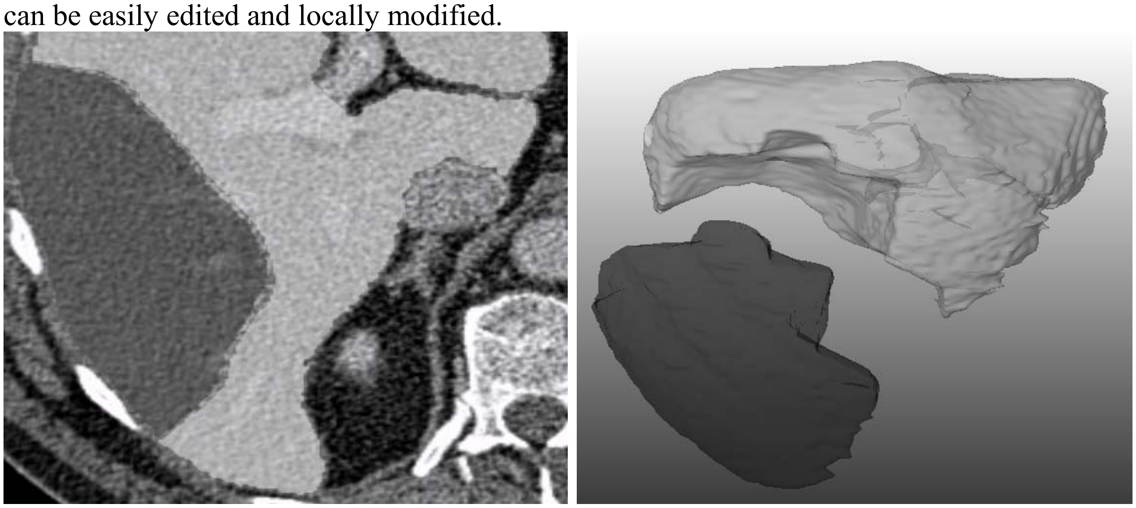

Fig. 2: Manual resection territory based upon the automatic proposal shown in Fig 1.

4. Planning of minimally invasive interventions

4.1 Decision support

Having segmented the intrahepatic structures one can support the physician in deciding whether the given case can be treated minimally invasively or not. A single LITT applicator can coagulate a volume having a diameter of up to 2.5-3.5 mm if hepatic perfusion is maintained. Larger tumors therefore require additional applicators, especially since it is generally tried to coagulate a volume consisting of the visible tumor and a security margin of 1 cm around it. Patients with tumors whose diameter is greater than 5 cm are generally excluded from minimally invasive interventions.

By automatically measuring the tumors' sizes our system creates as many applicators as necessary to fully destroy them. To ease the positioning, the applicators are automatically arranged in the form of a regular polygon around the corresponding tumor's centre of gravity and aligned to this tumor's longest main axis.

4.1 Applicator positioning

Planning of minimally invasive therapies aims at the optimal applicator placement to completely destroy the tumor while preserving surrounding healthy tissue.

For applicator placement, the user is provided with a synchronous 2D and 3D view on the segmented data as well as on the applicators. In 2D, the original data is transparently overlayed with the segmentation results, whereas the same colors are employed in 2D and 3D to communicate the relationship. Since it is also possible to combine the surface-rendered 3D-scene with volume rendering of the original dataset one can easily check whether any bony structures or main vascular branches lie within any applicator's path. This evaluation is additionally supported by presenting the user a histogram showing the gray-value distribution along the applicator's path. Prominent peaks are a reliable hint on either bones or contrast-enhanced vessels. Automatical positioning is supported in the previously described way, but if this setting does not meet the physician's requirements, the position and orientation can interactively be modified either mouse-driven or incrementally by means of the keyboard.

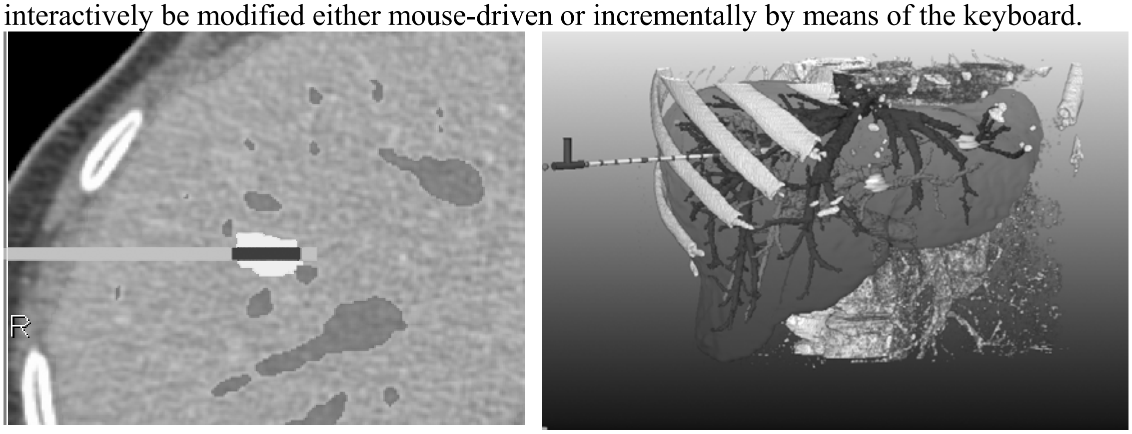

Fig. 3: Synchronous 2D and 3D views enable the user to quickly check if either bony structures or important vessels lie on an applicator's path.

4.2 Therapy simulation

To reliably predict shape and location of the damaged tissue, it is necessary both to segment all intrahepatic structures and to specify these structures' thermal and physical characteristics. Having defined the applicators' properties, such as energy and application time, a simulation of the therapy can be performed which precalculates the damaged tissue. The simulation itself is carried out by the previously mentioned LITCIT, which was modified so that the segmentation results can be directly used as an anatomical basis for the simulation of the heating. In detail, the LITCIT approximates the distribution of the photons emitted by the laser applicator with the help of a Monte-Carlo-Simulation and, based upon this, determines the temperature distribution as a result of photon absorption. Heat transport within the tissue is calculated by means of finite differences. For the evaluation, the damage distribution is visualized both in 2D and 3D in the delineated synchronous way. Analogously to resection analysis, the territory being affected by the necrosis of the damaged tissue is determined as additional decision support.

5. Results

By introducing the possibility to simplify the automatically determined resection proposals user acceptablity has been increased. This is also due to the fact that the strategy described correlates strongly with the way surgeons have planned in practice so far. The presented manual resection strategy is also used in cases of living donor liver transplantation.

First results of planning minimally invasive interventions show that for tumors or metastases being situated close to vascular branches there are significant differences in the resulting damage distribution if the vessels' cooling effect is taking into account. The importance of considering vessels in thermal ablation of tumors by minimally invasive therapies is currently being further explored in animal experiments.

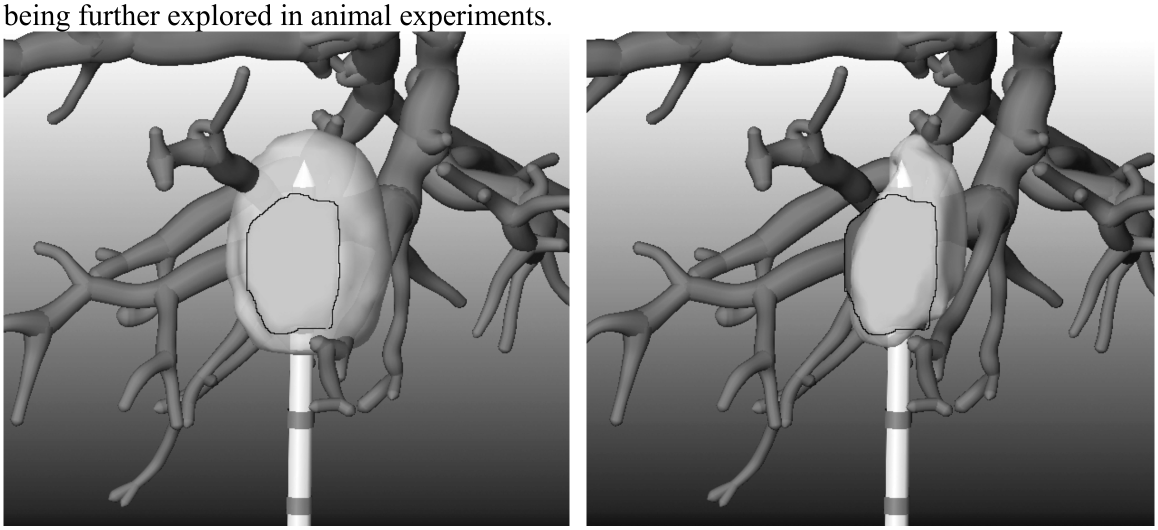

Fig. 4: Neglecting intrahepatic vessels in the LITT simulation (left) results in a lesion that fully encloses the tumor (outlined black), whereas the simulation that takes vascular structures into account shows that more energy is necessary to completely destroy the tumor due to the cooling effect of surrounding vessels.

6. Conclusion

The automatically generated resection proposals, as calculated by our system, are not always suitable. A combination of manual resection planning and automatic suggestions therefore seems to be the best way of tackling the problem. In our system, the surgeon can define and modify the resection based upon the automatically generated proposal by drawing few lines into the datasets.

An even more desirable solution, which is in the process of being developed, is to regard the resection proposal as an initial suggestion which can be refined interactively.

Regarding planning of minimally invasive interventions, the necessity for considering the intrahepatic vascular systems emerges, as our simulations show that their cooling can have a significant influence on the resulting damaged tissue.

References

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