# Towards a Workflow Oriented Software Assistance for the Radiofrequency Ablation

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**Abstract:** In recent years, radiofrequency ablation of liver tumors has become a serious alternative to surgical resection for unresectable colorectal metastases. The treatment success highly depends on an effective placement of the radiofrequency applicators into the tumor to get a sufficient coagulative necrosis. Therefore, several software tools have been developed for the support and planning of a good treatment strategy. The software solution proposed in this paper aims at the assistance of the radiologist at each stage of the ablation workflow, including the tasks of planning, intervention and treatment assessment.

## 1 Introduction

Due to recent advances in medical imaging, percutaneous image-guided ablative therapies using thermal energy have been developed as minimally invasive strategies for the treatment of focal malignancy [GGM00, MI01]. Among them, the radiofrequency (RF) ablation has taken a significant part in the clinical routine [SLG+01, PCB+04]. Because of its efficacy, combined with easy application and a low complication rate [MI01], RF-ablation has become one of the most important alternatives to surgical resection for the therapy of liver metastases as well as a complementary method to the treatment of liver malignancies [PCB+04].

To accomplish RF ablation, a high-frequency alternating electric field is induced in the tumor tissue, which causes a local resistive heating of the surrounding tissue by ionic agitation. This leads to cellular death as a result of irreversible protein denaturation. Several devices have been developed to obtain thermal lesions of sufficient sizes, which differ in the shape and the configuration of the RF applicators (single or clustered needle electrodes, umbrella configuration of electrodes, internally cooled applicator, monopolar or multipolar electrode configurations) and in the control algorithms of the RF generators [MI01, PTS+04].

**RF ablation software**

The thermo ablation therapy aims at the destruction of all tumor cells with a minimum amount of affected healthy tissue and without damaging adjacent vital structures. The thermal induced lesion commonly includes a safety margin of 0.5 to 1 cm to avoid microscopic foci of disease and positioning uncertainties [GGM00]. The success of the treatment highly depends on a careful planning, incorporating the right choice of the electrode placement. Several software tools have therefore focused on the planning of an optimized RF applicator positioning [VSP+03, CTS+03, VSG05, MCH+06] and the numerical estimation of the coagulative necrosis [Ste00, TSH+02].

In contrast to these specific solutions, our software aims at the assistance of the complete RF ablation workflow from treatment planning over ablation support to the assessment of the ablation result. Therefore, the application integrates software assistants with specific features for each of these three tasks, which will be described in the following chapter. Each of these assistants can be used separately at the corresponding stage of the treatment process. The main application controls the data exchange between the particular assistants as well as the storage of treatment settings and computational results.

The workflow oriented design of the software has been created in cooperation with physicians from the radiological departments at the university hospitals in Tübingen, Lübeck and Munich. Each of the software assistants has been developed under consideration of the requirements of clinical routine, i. e. easy user interaction and a high degree of automatic procedures in order to keep the physician from spending to much time at the computer.

## 2 Image guided radiofrequency ablation workflow

Image guidance is used in different ways during the RF ablation workflow [GGC+05]: During the *planning* step medical images (e. g. from CT or MR) are used to determine the tumor size and shape as well as its location within the organ in relation to blood vessels and critical structures (figure 1A). This knowledge is used to work out a treatment strategy and to plan a corresponding RF applicator placement.

Imaging during the *intervention* step can involve targeting, monitoring and controlling. The term "Targeting" describes the placement of the RF applicator into the tumor under image guidance, e. g. fluoroscopy CT or MR (figure 1B). "Monitoring" and "controlling" describe imaging techniques with which therapy effects can be visualized and improved during the procedure. Currently MR is the only modality with validated techniques for realtime temperature monitoring [GGC+05].

After the ablation has been completed, imaging can be used for the *assessment* of the treatment success, i. e. determination of the thermal lesion size, shape and location in comparison with the corresponding tumor data determined in the planning step (figure 1C). In the following sections we will present software assistants for planning and assessment of radiofrequency ablations. The image processing and visualization methods are optimized for CT and MR images, which can be received in DICOM format from the corresponding modalities as well as from a PACS archive system.
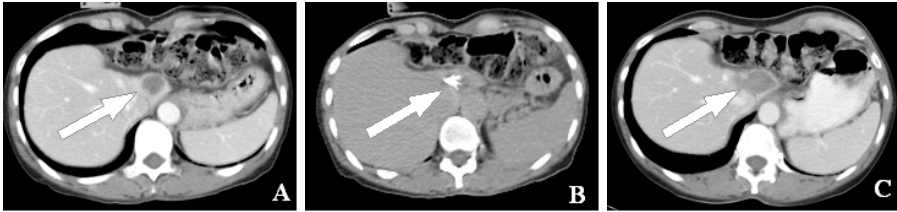
Figure 1: Three images presenting the three steps of the RF ablation workflow: (A) tumor location in a contrasted CT image, (B) probe placement in a fluoroscopy CT image and (C) thermo lesion assessment in a contrasted CT image

## 2.1 The planning assistant

The conceptual design of the planning assistant aims at a quick access to all useful information with just little interaction. Therefore a collection of image processing and visualization methods is provided, which work on the image data that has been acquired just before the intervention. Beside the familiar 2D image representation with its axial, sagittal and coronal views, a 3D visualization can be chosen for a more intuitive view of the scene and all computational results can be visualized in 3D as well as in 2D (figure 2). The usage of the planning assistant follows a step-by-step-strategy with the following elements:

1. *Tumor segmentation and quantification*: As described before, an effective treatment strategy strongly depends on knowledge about the tumor size, shape and location within the organ. Therefore we have integrated a fast and easy to use volumetric one-click-segmentation, which uses a morphological based region growing algorithm proposed in [KDB+04]. The calculation of one tumor mask only takes a few seconds, depending on the tumor size and the resolution of the input image data. The algorithm has been adapted to work on MR data as well as on CT data. The tumor shape can be corrected stepwise towards "irregular" or "roundish" by two corresponding buttons. A manual segmentation exists for cases, where the algorithm fails. The resulting tumor area will be represented as a colored overlay in the 2D slices and as a colored volume in the 3D visualization. The tumor volume and the maximum diameter axis are determined automatically. Additional quantification tools for distance measurement are provided too.

2. *RF applicator placement*: RF applicators can be placed in 2D as well as in 3D: For the placement in 2D slices, the applicator position is defined by two markers, which can be moved independently. The first marker defines the position of the center of the applicator's active zone, the second one marks the applicator shaft and thus defines the trajectory. A visualization of the applicator is projected onto the slices. In 3D, a visual model of the applicator can be picked with the mouse pointer and moved to the desired position. If it is picked at the shaft end, the spatial orientation can be changed. Applicators can be added or removed for different treatment settings. Currently only needle like applicator shapes are supported, in monopolar as well as in bipolar configurations.

3. *Local vessel segmentation*: To take cooling effects into account for the subsequent estimation of the coagulative necrosis, a segmentation of the vessel system in the vicinity of the center of the non-insulated applicator tips can be performed in a similar way as for the tumor segmentation: a mouse-click into one vessel starts an automatic segmentation algorithm, which is based on a bayesian background suppression of the liver tissue and a combination of thresholding and region growing to detect the vessels into the local neighborhood. The resulting vascular system is presented in 2D and 3D.

4. *Estimation of the coagulated necrosis*: After the placement of the RF applicators and the segmentation of the local vessel system, an estimation of the heat distribution and the corresponding thermal lesion can be performed. The computation is based on a finite element method as described in [KAP$^+$06] and follows a biophysical modeling based on the one proposed in [Ste00]. The computed lesion is visualized as a colored overlay in 2D and a colored volume in 3D.
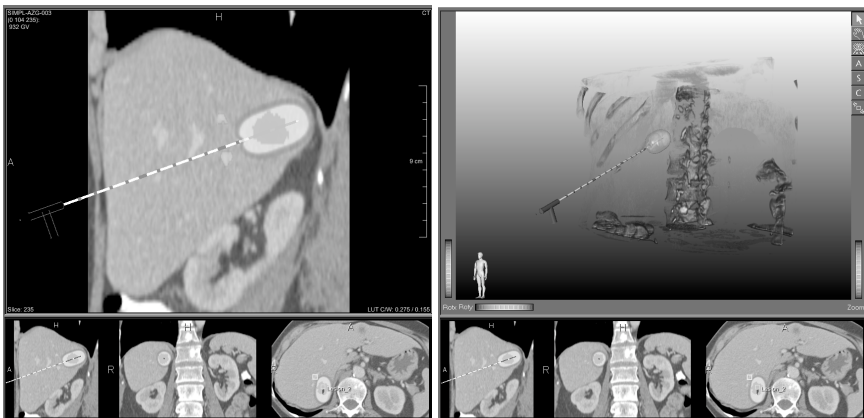


Figure 2: The planning assistant: Visualization of the planning steps in 2D and 3D, including the tumor segmentation mask and the estimated heat distribution according to an RF ablation with a bipolar RF applicator.

## 2.2 The assessment assistant

Post-interventional image acquisition is performed to assess the completeness of the ablation and to look for potential complications caused during the intervention. As a standard clinical assessment procedure the pre- and post-interventional images are compared sequentially on one monitor or parallel on two monitors to examine the embedding of the tumor into the coagulated area. If the embedding is complete, the ablation appears to be successful. Difficulties of this approach occur due to patient movement between the image acquisition times and possible deformations of the affected areas.
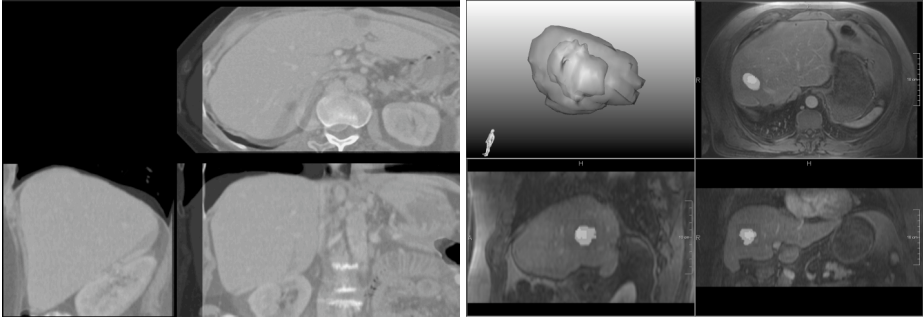
Figure 3: The assessment assistant: image registration (left) and result representation (right). The registration shows the overlays of the post-interventional image (bright) and the pre-interventional image (dark). The result representation visualizes the embedding of the tumor mask into the necrosis mask in two and three dimensions.

The purpose of our assistant is to provide methods for a reliable comparison of the tumor and the thermo lesion, based on image registration and quantification of the tumor area versus the necrosis area (figure 3). Like the planning tool, the assessment software follows a stepwise approach:

1. The pre- as well as the post-interventional image datasets are loaded and presented together in a parallel 2D-viewer configuration. Tumor segmentation masks are loaded and visualized together with the pre-interventional images. We use a color-coding to separate pre- from post-interventional data, i. e. data is colored according to the dataset it belongs to in all subsequent steps. For that, we use two colors with a high contrast to each other.

2. *Necrosis segmentation*: The segmentation of the coagulated necrosis is based on the same algorithm as the tumor segmentation in the planning assistant and thus works in the same way: The physician marks the center of the necrosis by a mouse-click, which starts the automatic segmentation. The segmentation result is presented as a colored overlay in the post-interventional image.

3. *Registration of pre- and post-interventional image data*: To simplify the assessment on the basis of pre- and post-interventional images, we use a straightforward registration of both datasets instead of a sequential or parallel comparison of these images. The aim is to get a fast, but adequate matching of the tumor's and coagulative necrosis' area within the affected organ for a subsequent comparative quantification of the segmentation masks. As an initial implementation we have integrated a rigid registration of the post-interventional image onto the pre-interventional image data. Both images are therefore overlaid in an orthogonal viewer, which shows the axial, sagittal and coronal view of the datasets. For separation, the layers are colored in the previously described way. In each view, the user can pick the post-interventional layer and match it to the pre-interventional layer using simple mouse interactions.

4. *Visualization and quantification*: For the concluding assessment of the ablation result, we provide a combination of 2D and 3D visualization: The colored segmentation masks of tumor and necrosis are overlaid in an orthogonal 2D viewer. A 3D visualization shows the correlated volumes of both segmentations. To quantify the intervention success, we perform an automatic surface distance measurement: The minimum and maximum distances between the tumor and the necrosis surfaces are computed. A "traffic light" color coding is used for visualization of the distances: 'Green' shows areas of ablation with adequate secure margin, 'Yellow' marks areas, where the margin is unsufficient and 'Red' tags areas of possible residual tumor.

## 3   Conclusion and future works

We presented an application, which assists physicians at the workflow of a radiofrequency ablation of hepatic tumors. Therefore we have created specific software assistants providing image processing and visualization methods adapted to the tasks of intervention planning and intervention assessment. The software has been installed at the radiological departments of the university hospitals in Tübingen, Lübeck and Munich for optimization and validation purposes. It is currently used within the scope of initial studies, which evaluate the efficiency of the software support of image guided RF ablations in the clinical routine.

Future works will concentrate on the development and integration of methods useful for the interventional task, particularly with regard to the on-line positioning of RF applicators under image guidance. Furthermore, methods for an effective automatic registration of pre- and post-interventional images are examined, which could replace the manual registration used in the assessment assistant so far.

## Acknowledgments

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