Software Tool for the Analysis of the Coagulation Zone from Multipolar Radiofrequency Ablation

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Abstract:

Percutaneous radiofrequency (RF) ablation is becoming a standard minimal invasive procedure for treatment of primary liver tumors. In clinical practice, knowledge about geometry and expected size of the coagulation is essential to prevent local tumor recurrence. Particularly the heat-sink effects of large vessels in the vicinity of the electrode may lead to a smaller size of the coagulation zone.
For the evaluation of multipolar RF ablation studies with ex-vivo porcine livers, a novel software tool is presented. The tool supports manual contouring of the coagulation in digital photographs from liver slices. Based on geometric measurements of the RF applicators, deformations of the liver specimens are compensated. Furthermore, the software tool supports automated quantification of a large number of experiments.

Keywords: Radiofrequency Ablation, Quantification, Cooling effect, Multipolar RFA

1   Purpose

Image-guided ablation therapies using thermal energy, particularly radiofrequency ablation (RFA), have been developed as a minimal invasive alternative in contrast to the surgical resection of liver tumors[1]. Due to its common technical procedure, low complication rate and low cost, RFA has taken a significant part in clinical practice. The principle of the RFA is the placement of RF electrodes into the tumor. Subsequently, a high-frequency electric field is induced, which causes a local heating and leads to a coagulation necrosis as a result of cell destruction. The choice of an appropriate applicator type and the exact placement of the electrodes is essential to achieve complete destruction of cancer cells with respect to the heat-sink effect of cooling blood vessels, located in the vicinity of the tumor[2].

To increase the ablation zone, up to three bipolar applicators can be placed close to each other and simultaneously connected to a single generator[3]. In such a multipolar setting, the electrical field is induced in a round-robin fashion between all possible electrode combinations, resulting in an extended ablation zone. Typically, the applicators are placed around the target lesion in order to maximize the combined coagulation zone.

To quantify the cooling effect of hepatic vessels in the liver, ex vivo experiments with bipolar RF applicators in porcine livers have been analyzed[4,5]. However, heat-sink effects from multipolar RFA have not been taken into account. The contribution of this work is a software tool to support comparative quantification of the cooling effects in multipolar ex-vivo experiments.

2   Methods

For this software, it is assumed that slice images of the specimen are digitally photographed orthogonal to the applicator needle. Since the real-world pixel size is not stored in images taken with digital cameras, this information has to be added manually in the software. For that, it is required, that the photographs of the specimen also show a scale, for instance a sheet of millimeter paper. The software is parted into two sub-applications: the first application allows to create manual segmentation masks of the ablation zones and to store them in a database, the second application allows to automatically analyze the ablation zones stored in the database with regard to the cooling effects of the vascular system.

In the first step of the software, the photograph of the specimen is loaded and calibrated. For that, a rectangle has to be drawn onto the photographed sheet of millimeter paper and the current size has to be specified. After this step, transformation of pixel scale to world scale is defined, allowing quantification based on the photograph.

In the next step, the positions of the RF applicators as well as the cooling vessel have to be determined in the photograph. For that, circles with the current radii of the applicators and vessel are added by mouse interaction in the image viewer, respectively. Goal of this procedure is to exactly specify the geometric setting of the photograph.

Because the geometric setting of the photograph does not exactly correspond to the original geometric arrangement of the RF applicators and vessel in the experiment, the photograph has to be deformed. Despite the stable geometric arrangement in the experiment, the deformation in the photograph is related to the cutting procedure and the soft tissue property of the liver. To allow comparison of different experiments, all photographs have to be deformed to the original geometric setting. Based on the specified objects in the image and the well-known geometric setting in the experiments, a thin-plate spline landmark registration[6] is used to calculate the transformation. Based on this transformation, the image of the photograph is deformed.

After image deformation, the coagulation necrosis has to be segmented. The goal is to classify the white zone as described in the study by Ng et al.[7]. Findings of this study demonstrate that complete cellular destruction can be achieved within the whole zone of RF ablation to the ablative margins of the white zone. In the software, drawing a contour around the white zone allows to segment the ablation zone. The contour's shape can be changed afterwards by mouse

interactions. If the tissue around the vessel could not be ablated due to the heat-sink effect, a second contour may be drawn in order to classify native healthy tissue inside of the ablation zone. The complete procedure from calibration to contouring is repeated for every specimen leading to a large database of segmented ablation zones with corresponding geometric settings. Figure 1 shows the determination of RF applicators and vessel, the deformation and the contouring.
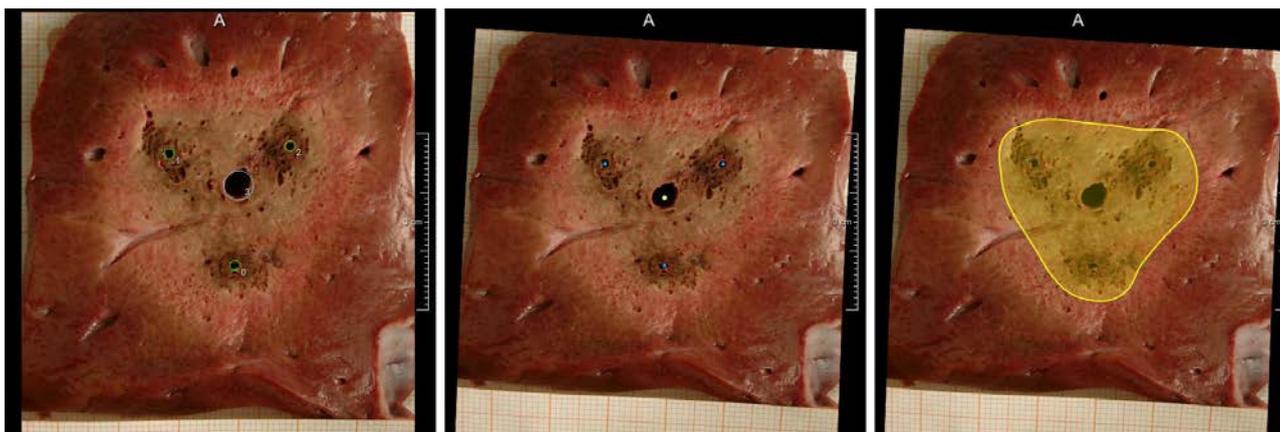
Fig. 1: Left: the specified RF applicators and the vessel. Middle: the image after deformation to the original geometric setup. Right: drawn contour around the white zone on top of the deformed photograph.

The second part of the proposed software supports the quantitative and qualitative analysis of the stored ablation zones. Based on the database, every stored experiment can be loaded and analyzed. In order to analyze the heat-sink effects, a ground truth ablation zone mask has to be specified, i.e. an experiment without vascular cooling.

In the first step of the application, arbitrary numbers of experiments without vascular cooling are loaded in order to calculate a robust ground truth mask. The goal is to minimize the variation introduced by the different experiments and resulting segmentation masks. For that, shape-based averaging[8] is used to calculate a robust ground truth mask.

In the next step, any stored experiment can be loaded and compared with the ground truth. Since the geometric setup is also stored in the database, the ground truth and the measured experiment can be visualized together. The ground truth is shown in the viewer as a yellow contour superimposed onto the photograph. The measured ablation zone mask is displayed as a blue contour. Quantitatively, the area of the ground truth is automatically compared with the area of the measured ablation zone. Also, the area of the intersection is calculated. For a qualitative description of the cooling effect, the fraction of the cooling effect regarding the ground truth is represented in dependency to the distance to the vessel. For that, the following formula is evaluated for a specified number of circles around the vessel: (GT / AZ) – GT, whereas GT denotes the area of ground truth and AZ the area of the measured ablation zone pixels.

Thus, a value of 1 corresponds to tissue with vascular heat sink, i.e. a circle with ground truth but without measured ablation zone, and 0 corresponds to tissue without vascular cooling. The resulting values per circle are displays in a graph. In order to support fully automated processing of the complete database, a batch processing method is integrated. The batch processing automatically loads all photographs and corresponding segmented ablation zones one after the other,

and calculates the above-mentioned analysis. Subsequently, the results are stored in a CSV table, which may be further processed in spreadsheet applications such as Excel. Figure 2 shows a screenshot of the analysis application.
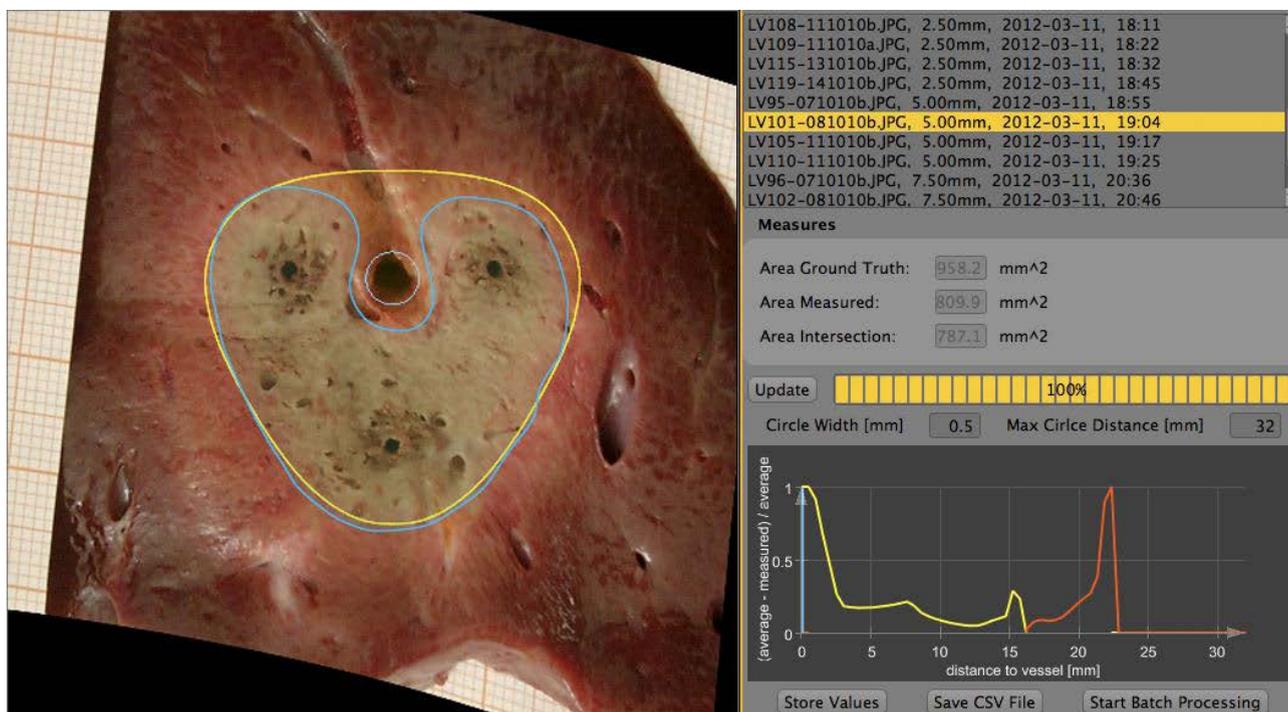
Fig. 2: Screenshot of the analysis software. The yellow contour shows the averaged ground truth ablation zone

without cooling. The blue contour represents the ablation zone of the selected experiment. Quantitative measures (area in mm^2) as well as the processed curve are displayed in the graphical user interface.

3   Results

The proposed software has been used in an ex-vivo study with porcine livers. Using an aiming device, three RF-applicators were induced in parallel into the liver tissue and a coagulation zone was ablated. A bipolar RFA system was used for the ablation. Three RF applicators with 20 mm distance to each other were used (CelonProSurge 150-T20, Celon AG Medical Instruments, Germany). A power of 60 W was applied until an energy application of 40 kJ was reached. All RF applications were performed at room temperature. In order to simulate large perfused vessels, glass tubes with diameter of 5 mm were utilized. The glass tubes were introduced with the aiming device with following distances to the center of the three applicators: 0, 2.5, 5, 7.5, and 10 mm. A roller pump was connected in order to create flow of saline in the tube. The flow rate was not varied because previous studies already show that the influence of the flow rate can be neglected. After ablation, the livers were cut through at the center of the electrode perpendicular to the applicator.

Using the presented software, the ablation zones of 6 experiments for each geometric setup (in all 30) were manually segmented by a medical expert. The complete processing took approximately 5 minutes per case. Additionally, 5 experiments without cooling, i.e. with disabled pump, were performed. To determine the ground truth, the corresponding ablation zones were averaged as described above. Subsequently, all 30 experiments were automatically analyzed with the batch-processing mode within 9 minutes (circle with: 0.5 mm).

As a preliminary result of the study, the segmented ablation zone masks for each geometric setup are averaged and compared with the ground truth. Figure 3 shows the averaged mask of the ground truth as well as the masks of the cooling experiments with 0, 2.5, 5, 7.5, and 10 mm distance of the glass tube to the applicator's center. In the image, the heat-sink effect around the class tube can be clearly observed. Further quantitative and qualitative results have already been compared and will be published in the near future

57
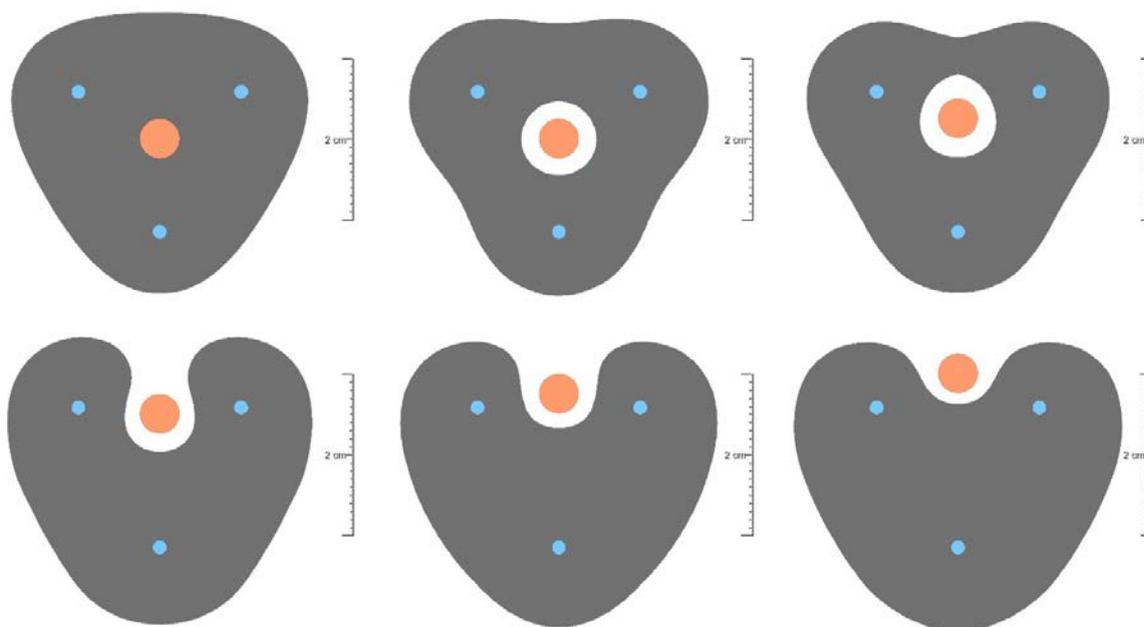
Fig. 3: Averaged ablation zone masks from ex-vivo experiments with three RF applicators and glass tube. From left to right upper row: ground truth, 0, and 2.5 mm distance of the glass tube to center of probes. From left to right lower row: 5, 7.5, and 10 mm distance.

4   Conclusions

In this work, a software tool for contouring of multipolar ablation zones in digital photographs of liver specimens and subsequent quantitative as well as qualitative analysis is presented. The software supports calibration, deformation and contouring of the photograph. Furthermore, a fully automatic analysis based on an averaged ground truth mask is presented. The software has been used in experimental ex-vivo study for analysis of the heat-sink effect for multipolar RFA, but is not restricted to ex-vivo or RFA. In future experiments, in-vivo ablation zones will be analyzed after resection of bovine livers and subsequent photographing of the specimens. A further application of the software tool will be the analysis of multi antenna microwave ablations and the comparison with RF ablation zones.

5   References

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