MRI-Guided Liver Tumor Ablation - A Workflow Design Prototype

J. Alpers[1,2], B. Hensen[2,3], F. Wacker[2,3], C. Rieder[4], C. Hansen[1,2]

[1] *Faculty of Computer Science, Otto-von-Guericke University, Magdeburg, Germany*
[2] *Research Campus STIMULATE, Otto-von-Guericke University, Magdeburg, Germany*
[3] *Hannover Medical School, Department of Diagnostic and Interventional Radiology, Hannover, Germany*
[4] *Fraunhofer MEVIS, Bremen, Germany*

Contact: jalpers@isg.cs.ovgu.de

Abstract

Thermal ablation procedures such as radiofrequency ablation have become a clinically accepted treatment method for liver tumors. Using image guidance like magnetic resonance imaging (MRI), a needle-shaped instrument is navigated to the target position aiming at a complete destruction of the focal liver malignancies. Planning the intervention, navigating the instrument to the target position, and monitoring the ablation of the malignant tissue are currently three separated steps during MRI guided interventions. This is hampering the clinical workflow and results in an unnecessary amount of additional work for the clinicians due to data export and import or mental data transfer.
We introduce a prototype for a combined workflow design for interventional radiology using MRI guidance. The prototype is able to guide the radiologist during planning, navigation and monitoring the ablation without manual data transfer. Evaluation with four clinical experts shows a strongly positive trend to the combined workflow design.

Keywords: Workflow, Navigation, Monitoring, Radiofrequency Ablation, MRI Guidance

1 Problem

In the recent years needle-based percutaneous liver tumor ablations, such as radiofrequency ablations, have become a promising alternative to surgical resection [1]. During these interventions a needle-shaped instrument has to be placed inside the malignant tissue. After reaching the target structure, energy is induced in the tip of the instrument leading to a temperature rise in the surrounding tissue. A temperature of $> 60°$C results in an immediate cell death and coagulation necrosis. Correct planning of the therapy, accurate positioning of the instrument, and real-time monitoring during the ablation are very crucial for a successful treatment. Insufficient execution of any of the previously mentioned steps may lead to malignant tissue outside of the coagulation necrosis and therefore a failed therapy [2]. Accurate planning of these interventions has been mostly covered in the past years [3], [4]. Nevertheless, the transfer of the planned data into the intervention room still needs a lot of attention. One of the reasons may be the hampering of the fast data transfer due to heterogeneous software and hardware systems in the intervention room. In this case the planning data has to be manually exported and imported into the navigation software, if available. This time consuming task results in additional work for the radiologist and the assistants. The instrument placement may be guided by fast MRI sequences to support the radiologist [5]. Using this image modality, several navigation systems have been developed to provide intra-interventional information to the performing radiologist [6]–[8]. Rothgang et al.[9] tried to improve the workflow during navigation but did not provide a proper monitoring during the ablation of the tumor. MR thermometry has been used to display the temperature of the tissue surrounding the instrument tip during ablation [10]. Unfortunately, these sequences have to be planned very carefully in advance, which results in a lot of additional work for the radiologist and the assistants again. In addition, the acquisition of MR images during the ablation is usually omitted because of known interferences between the radiofrequency generator and MR scanner [11], [12]. Nonetheless, a missing monitoring of the coagulation necrosis may lead to either an insufficient or excessive ablation. Former results in a failed therapy, whereas the latter results in a successful treatment but also a higher patient trauma due to the additional coagulated tissue.

In this work, we propose a prototype for a workflow design for MRI guided thermal tumor ablation combining planning, navigation, and monitoring of the therapy, which is based on the SAFIR (Software for Interventional Radiology) toolbox [13]. This workflow is aiming at reducing the mental workload of the performing radiologists by eliminating the transfer steps between the three steps of planning, navigation and monitoring. To the best of our knowledge, there is no system available yet combining these three steps for MRI guided interventions without a manual transfer of the data from one step to another.

The outline of this paper is as follows: Section 2 describes the planning, navigation, and monitoring parts of the presented prototype as well as the evaluation of the proposed workflow with the help of four clinical experts. Section 3 shows the results of the evaluation. Section 4 shows a critical discussion of the results showing advantages and disadvantages of the proposed prototype and Section 5 concludes this paper with a short summary and a look ahead.

2 Material and Methods

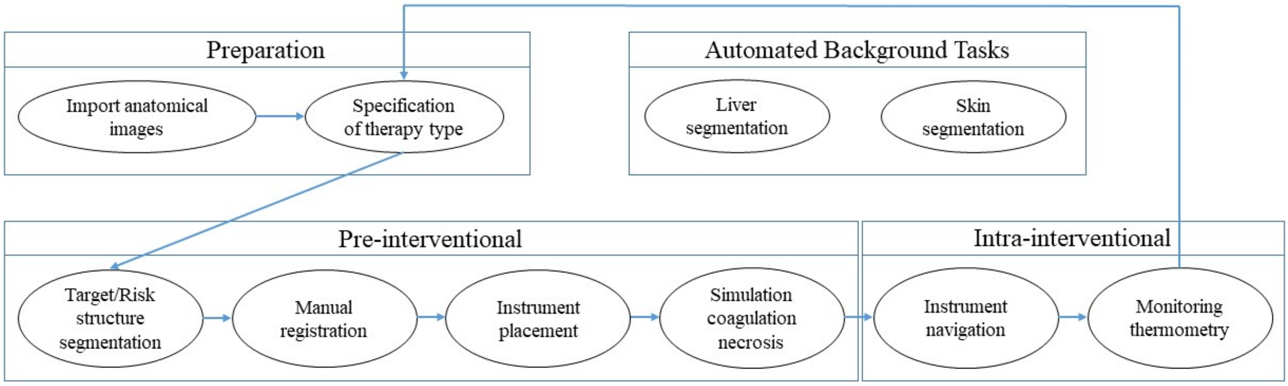

Figure 1: *Sketch of the basic workflow. Preparation takes place before the actual intervention. Automated background tasks take place during therapy creation. Pre-interventional describes the planning phase. Navigation and monitoring cover the intra-interventional workflow phases.*

In general, the proposed workflow consists of four different steps. The preparation of the intervention describes the import of already existing DICOM images via file system or DICOM node, e.g. previously acquired planning data sets or other anatomical data. Afterwards, the therapy will be created specifying the type of intervention, which will be performed. Depending on the therapy type created, automated background tasks will perform common preprocessing of the data like liver segmentation or segmentation of the patient skin mask, which may be used as an initial input for further image processing methods during the navigation or monitoring. The pre-interventional planning is part of the sequential workflow starting with the segmentation of target as well as risk structures and the manual co-registration of different anatomical data sets if necessary. The instrument placement allows for choosing an optimal trajectory path to reach a selected target structure followed by a simulation of the coagulation necrosis to verify if the tumor can be completely ablated with the chosen target point. During intervention, continuous MR images are acquired to guide the clinicians during instrument insertion. After reaching the desired target point, a thermometry sequence allows for monitoring of the tissue temperature during ablation. A graphical illustration of the workflow can be found in Figure 1.

2.1 Planning

The planning phase of our workflow consists of an automated preprocessing and four manual steps: segmentation, manual registration, instrument placement and simulation. The preprocessing covers the initial segmentation of the patient skin mask and the liver. The patients skin mask can be visualized during instrument insertion to aid the performing radiologist during the task of finding the correct incision point. The liver mask, in addition, may be used for additional image processing in the future as an initial region of interest, e.g. for instrument detection during the navigation phase. The tumor and additional risk structures such as vessels are extracted using semi-automatic segmentation methods. An accurate segmentation of risk structures allows the radiologist to keep track of them during navigation and therefore bypass them without damaging them. In case the patient is re-positioned after the initial planning, image acquisition or the target organ has moved due to respiration the following intra-interventional image has to be manually co-registered to the planning data set. During path planning, an optimal access path and trajectory for the instrument insertion has to be found. To determine an accurate path, various virtual instrument models can be manually placed and aligned inside the planning data set. The trajectory itself is defined by the center of the instruments ablation zone and the incision point. The planning of the instrument position is crucial to avoid impenetrable structures such as bones or other critical risk structures such as the lung or vessels. During path planning, the performing radiologist defines a target point to completely ablate the tumor. To simplify the placement, ellipsoidal ablation zones

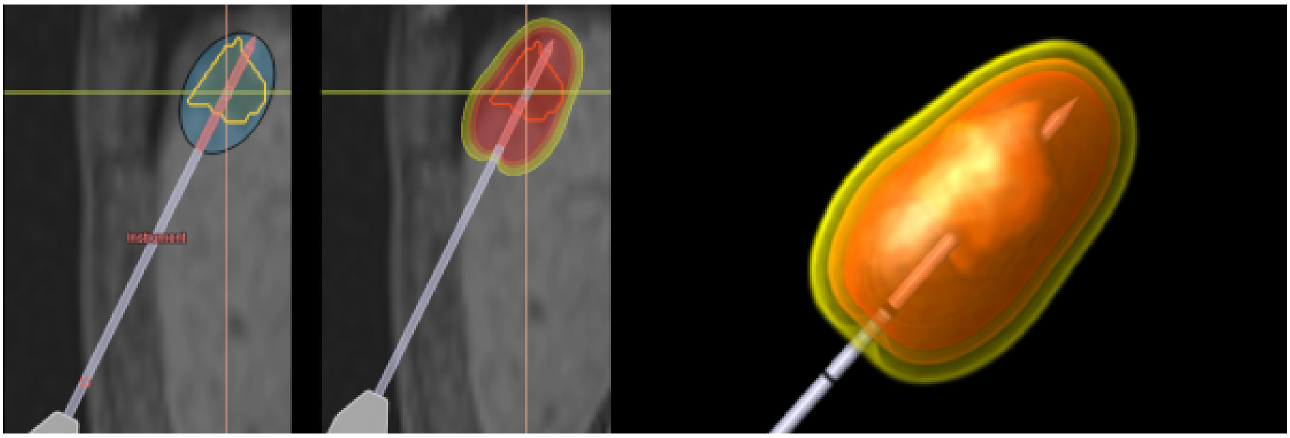

Figure 2: *Instrument placement. Left: Instrument including ellipsoidal ablation zone covering the whole target structure (tumor). Middle: Patient-specific numerical simulation of the thermal field. Right: 3D representation of the thermal field for better observation.*

as specified by the vendors are displayed around the instrument tip. After instrument placement, a numerical simulation of the ablation zone allows for a patient-specific display of the coagulation necrosis. If the simulation shows an incomplete overlay of the tumor the clinician may look for a better position or adjust the time of the therapy. An illustration of the instrument placement can be seen in Figure 2.

2.2 Navigation and Monitoring

After planning the intervention, the instrument has to be placed at the specified target position. Especially if more than one instrument has to be placed in a target structure the risk of excessive thermal coagulation is increasing due to the overlapping ablation zones. To guide the performing radiologist during insertion MRI guidance is used to verify the current position of the instrument inside the human body. The SIEMENS Scanner Remote Control (SRC) interface was used to offers full access to the MR scanner including readout of the image data stream and modifying the present sequences. Our current workflow offers three different image plane positions during navigation showing three different time steps of the current instrument position and the surrounding tissue (see Figure 3). The central image plane is aligned with the current instrument position and orientation to provide a good visibility of the instrument intersection along the main axis. To take care of out of plane angulation a ventral and dorsal slice are also visualized for better spatial perception. The update rate is set to 500ms for each slide independently offering a resolution of 128 x 128 pixel and a pixel spacing of 2.5mm / 2.5mm in X and Y direction. Using the SRC interface we are able to adjust these planes according to the needs of the radiologist at any time during the instrument insertion.

After instrument placement, the ablation of the tumor should be monitored to avoid an insufficient or excessive coagulation necrosis. MR thermometry is a known method to get information about the temperature inside a voxel of the dataset. To achieve this, a phase image is acquired prior to the intervention. From this reference image the following intra-interventional phase images are subtracted during the ablation. This results in a phase difference over the time, which is linear to the temperature of the tissue. To improve the accuracy, several reference images may be acquired and averaged to reduce e.g. motion artifacts. Currently, the image plane position and orientation to acquire the phase images have to be planned very carefully in advance, which is very time consuming and exhaustive. Due to the SRC interface integration we are able to modify the image plane position and orientation automatically during intervention providing a better support for the radiologist by aligning the position and orientation with the instrument. The generated phase difference images are presented as an overlay on top of the corresponding slice in the planning data set (see Figure 4).

2.3 Evaluation

The presented workflow prototype was evaluated with the help of four medical experts who are at least familiar with needle-based percutaneous interventions. For evaluation purpose the workflow was simulated using real intervention data from one patient with hepatocellular carcinoma and liver cirrhosis. The patient was previously treated with ablation and transarterial chemoembolisation but showed tumor recurrence at two sites of the liver. The shown recurrence was treated under MRI guidance because of excellent visibility of the tumor and the possibility of a risk structure avoiding trajectory (lung). Regarding the monitoring we did not have the

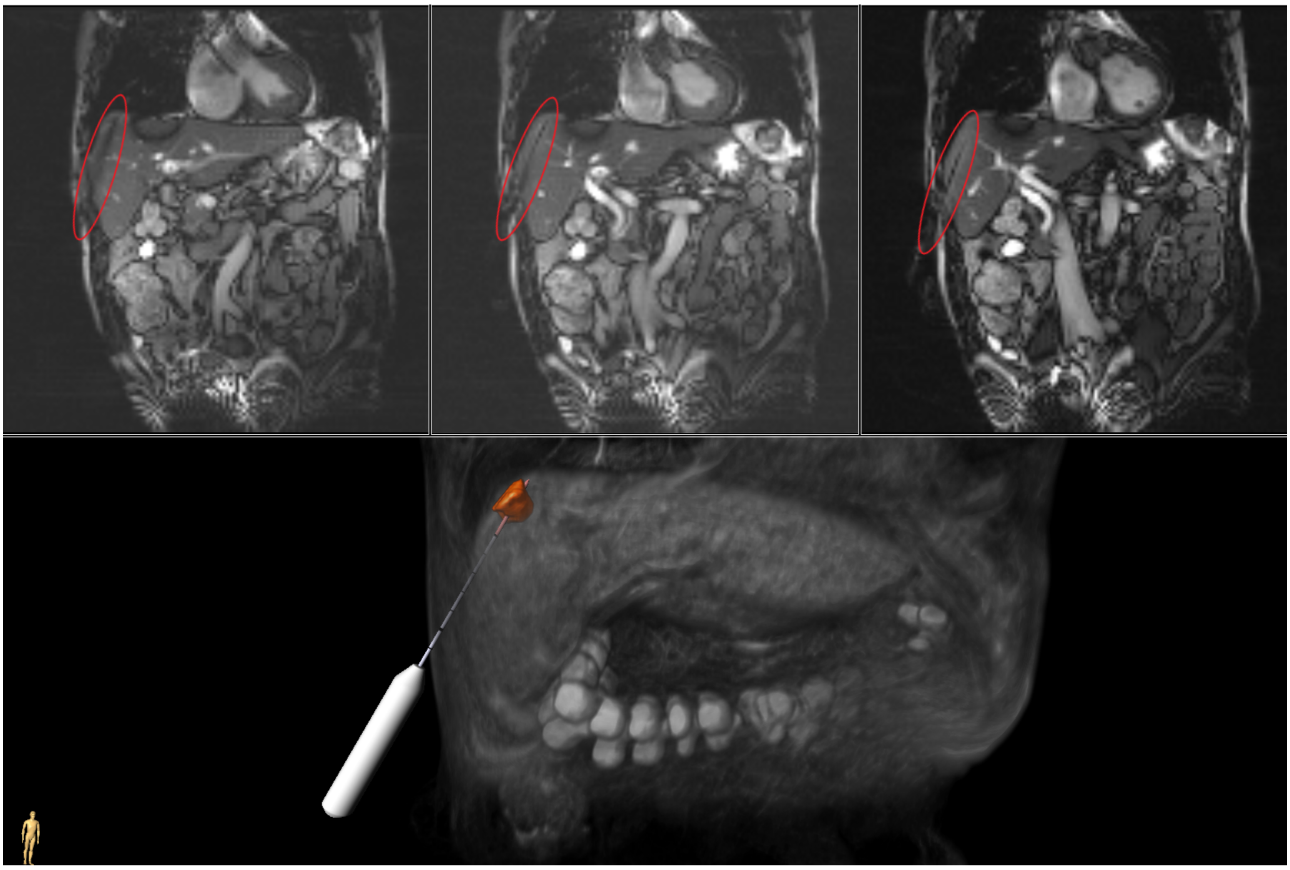

Figure 3: *Mosaic view during the navigation. Red circles indicate instrument position in different time steps. Top left: Pre-slice. Top middle: Image plane corresponding to the instrument orientation and position. Top right: Post-slice. Bottom: 3D-View showing the planning data set to evaluate the instrument position.*

chance to use real thermometry data due to insufficient quality of those. To solve this issue, the thermometry overlay was simulated and approximated to the ablation zone specified by the instrument vendor to offer a whole workflow during evaluation. To reduce the bias caused by the user interface the workflow was presented as a short video showing all steps for planning, navigation and monitoring. In addition, two questionnaires were created and handed out to the experts. The first questionnaire was handed out before the workflow video was shown, asking about the degree of expertise regarding needle-based interventions, the expertise regarding MRI guided interventions in particular and the advantages and disadvantages of the state of the art workflow. In addition, we asked for the rough number of interventions performed in the last year. After filling out the questionnaire, the participants watched the video. Afterwards, they were handed out the second questionnaire asking about the advantages and disadvantages of the proposed workflow, particular wishes for better support and guidance and other comments or suggestions to improve the workflow. All four experts rated their experience regarding needle-based interventions at least as "high" or "expert" as stated in the questionnaire. In average they performed roughly 250 interventions in the past year supporting their stated experience. Regarding MRI guided interventions, in particular, the experience ranged from "low", "medium" and "high" to one participant who stated that he was an "expert" in this field performing roughly 50 interventions in the last year.

3 Results

Regarding the current workflow for MRI guided interventions one of the main advantages stated was the absence of contrast agent during planning (visibility of small lesions) and monitoring (good visibility of the ablation zone). The real-time instrument guidance using fast MRI sequences and the absence of radiation were also stated as positive aspects. In addition, the availability of thermometry sequences for ablation monitoring and the free angulation of imaging planes (especially useful for lesions in the hepatic dome) are also two major advantages. Nonetheless, the limited space and therefore limited active interaction by the interventionist and the accessibility of the patient are a big drawback. It was also stated that the manipulation of the imaging

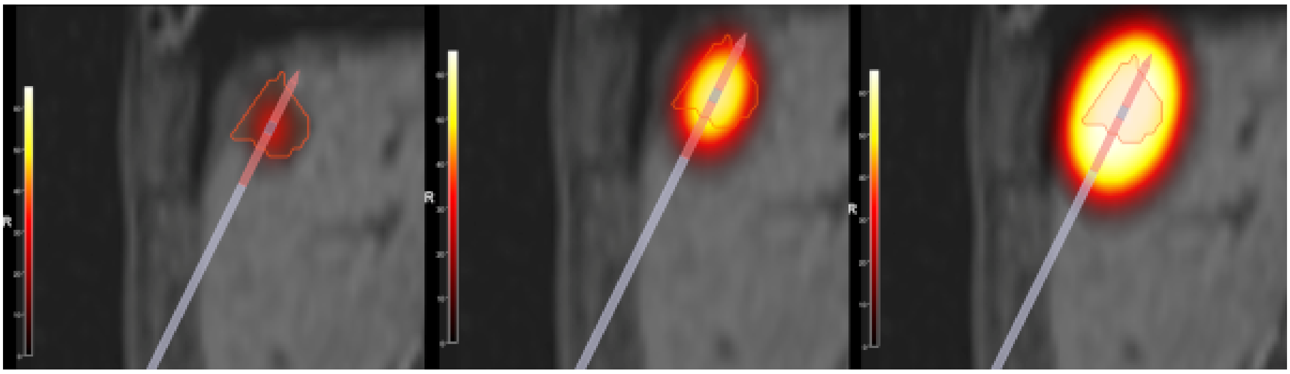

Figure 4: *Different time steps during the simulated thermometry monitoring of the intervention. Left: Beginning of the therapy. Middle: Half way into the therapy. Right: End of the therapy.*

planes only from the host computer is troublesome. Due to this, the performed interventions tend to be very time consuming and require an experienced technician and a very good communication. Furthermore only a few devices are available for use in the MR room.

Our proposed workflow was evaluated regarding possible benefits and downsides as well. First of all, the participants stated that the shown workflow will possibly lead to faster interventions because all intermediate steps are wrapped in one software. In addition, the procedure planning may be easier during path planning. The biggest advantage was said to be the possibility of safer interventions using the thermometry monitoring. The participants assume that the ablation zone can be controlled better leading to a more reliable assessment of the ablation outcome. Two out of the four experts did not see any disadvantages of the proposed workflow whereas the other two where concerned about the respiration motion during instrument placement and the monitoring of the ablation zone. The actual size of the ablation zone depends on several factors (fat content of the liver, previous embolization, fibrosis and others). In addition, it was stated that the time for the data transfer may result in a delay, e.g. during live navigation of the instrument.

4 Discussion

As mentioned previously, the time for performing an intervention may be reduced during our workflow, which would be a benefit for both, the performing radiologist and the patient. The all in one workflow offers a faster intervention and a help during planning and instrument placement. Because this was one of the main goals of the proposed workflow this outcome is not surprising. The other aim was to provide a good accessibility for an accurate tumor monitoring. This was as well said to be a very positive factor of the workflow design. Nonetheless, there are still some parts left for better observation. Especially the real-time monitoring using thermometry sequences needs to be treated with caution. Currently, only 2D thermometry images are available in our setup, which may give a good observation of the coagulation necrosis in the current image plane but not with respect to the whole target structure. This problem needs to be addressed in the future. One solution might be a pseudo 3D thermometry by acquiring several 2D phase images rotated along the current instrument axis and interpolating the intermediate image planes. To achieve this, we need to make sure that the image acquisition is sufficiently fast enough. Additionally, expiration motion may cause problems during instrument insertion. We currently assume a breath holding state but it would be more suitable to either track the motion during breathing or integrate deformation models into our software to compensate this movement. Another possibility would be to extract the liver contour in the intra-interventional images and compare them to the corresponding liver intersection in the planning data. In this case we might give the clinician an information about the current breath state of the patient allowing for choosing the perfect moment for instrument insertion. To also guide the radiologist during instrument insertion a fast segmentation of the instrument in the intra-interventional images should be integrated into the workflow. The elongation of the trajectory and the orthogonal visualization along this trajectory were suggestions during the evaluation of the workflow, which may help the radiologists even more during insertion.

Even though there are still many parts to take care of, the proposed workflow was rated positively by the experts including good suggestions for further improvement. In general, the disadvantages seem to be less compared to the current clinical workflow for MRI guided interventions.

5 Conclusion

In this work, we introduce a new workflow design for needle-based MRI guided percutaneous liver tumor ablations combining the planning, navigation and monitoring phase in a capsulated workflow. We used the SAFIR toolbox for planning of the intervention in combination with the SIEMENS SRC interface for real-time MR scanner access to manipulate the running sequences during navigation and monitoring.

We evaluated our design with the help of four clinical experts who are highly experienced regarding needle-based interventions in general and moderately experienced with those interventions under MRI guidance. Evaluation shows a strongly positive trend towards our new workflow design in comparison to the current workflow. Nonetheless a few drawbacks were stated, which will be part of our future research.

However this workflow design is robust platform for our future development. This may include the development of suitable instrument detection algorithms, visualization techniques for navigation guidance and a pseudo 3D thermometry approach for better ablation zone assessment.

6 Acknowledgement

The work of this paper is partly funded by the Federal Ministry of Education and Research within the Forschungscampus STIMULATE under grant number 13GW0095A.

7 References

[1] J. Hof, M. Wertenbroek, P. Peeters, *et al.*, “Outcomes after resection and/or radiofrequency ablation for recurrence after treatment of colorectal liver metastases,” *British Journal of Surgery*, vol. 103, no. 8, pp. 1055–1062, 2016.

[2] P. L. Pereira, “Actual role of radiofrequency ablation of liver metastases,” *European radiology*, vol. 17, no. 8, pp. 2062–2070, 2007.

[3] C. Rieder, M. Schwier, A. Weihusen, *et al.*, “Visualization of risk structures for interactive planning of image guided radiofrequency ablation of liver tumors,” in *Medical Imaging 2009: Visualization, Image-Guided Procedures, and Modeling*, International Society for Optics and Photonics, vol. 7261, 2009, p. 726 134.

[4] R. Khlebnikov, B. Kainz, J. Muehl, *et al.*, “Crepuscular rays for tumor accessibility planning,” *IEEE transactions on visualization and computer graphics*, vol. 17, no. 12, pp. 2163–2172, 2011.

[5] S. Clasen and P. L. Pereira, “Magnetic resonance guidance for radiofrequency ablation of liver tumors,” *Journal of Magnetic Resonance Imaging*, vol. 27, no. 2, pp. 421–433, 2008.

[6] M. M. Arnolli, N. C. Hanumara, M. Franken, *et al.*, “An overview of systems for ct-and mri-guided percutaneous needle placement in the thorax and abdomen,” *The International Journal of Medical Robotics and Computer Assisted Surgery*, vol. 11, no. 4, pp. 458–475, 2015.

[7] S. Clasen, A. Boss, D. Schmidt, *et al.*, “Magnetic resonance imaging for hepatic radiofrequency ablation,” *European journal of radiology*, vol. 59, no. 2, pp. 140–148, 2006.

[8] T. Maeda, J. Hong, K. Konishi, *et al.*, “Tumor ablation therapy of liver cancers with an open magnetic resonance imaging-based navigation system,” *Surgical endoscopy*, vol. 23, no. 5, p. 1048, 2009.

[9] E. Rothgang, W. D. Gilson, F. Wacker, *et al.*, “Rapid freehand mr-guided percutaneous needle interventions: An image-based approach to improve workflow and feasibility,” *Journal of Magnetic Resonance Imaging*, vol. 37, no. 5, pp. 1202–1212, 2013.

[10] U. Kägebein, O. Speck, F. Wacker, *et al.*, “Motion correction in proton resonance frequency–based thermometry in the liver,” *Topics in Magnetic Resonance Imaging*, vol. 27, no. 1, pp. 53–61, 2018.

[11] A. H. Mahnken, A. Buecker, E. Spuentrup, *et al.*, “Mr-guided radiofrequency ablation of hepatic malignancies at 1.5 t: Initial results,” *Journal of Magnetic Resonance Imaging: An Official Journal of the International Society for Magnetic Resonance in Medicine*, vol. 19, no. 3, pp. 342–348, 2004.

[12] G. Gaffke, B. Gebauer, F. D. Knollmann, *et al.*, “Use of semiflexible applicators for radiofrequency ablation of liver tumors,” *Cardiovascular and interventional radiology*, vol. 29, no. 2, pp. 270–275, 2006.

[13] A. Weihusen, F. Ritter, P. L. Pereira, *et al.*, “Towards a workflow oriented software assistance for the radiofrequency ablation.,” in *GI Jahrestagung (1)*, 2006, pp. 507–513.