Milica Bulatović*, Pascale Tinguely, Stefan Weber, Iwan Paolucci

Thermal ablation of irregular tumor shapes using robotic needle guidance

Abstract: When it comes to percutaneous thermal ablation, lack of treatment standardization gives poor results for treatment of larger and irregularly shaped liver tumors. To address this need, we have introduced a prospective solution consisting of dynamic ablation energy delivery with reference to robotically driven ablation needle. Our results demonstrate its clinical applicability by creating ablation shapes derived from clinical cases in a polymeric phantom and give a first look into its implementation.

Keywords: robotic ablation, interventional oncology, liver tumors, image-guided therapy

1 Introduction

Percutaneous thermal ablation appears as a good treatment option for patients suffering from unresectable malignant liver tumors [1]. Yet, for the most part, the treatment is not standardized, and it is still widely used only with palliative intent [2]. For instance, tumors that are larger in size or irregular in shape, as well as those that are in critical locations, are difficult to treat safely and efficiently with conventional ablative techniques [3]. Therefore, these cases seek particular attention concerning the accuracy of ablation needle placement, and the effectiveness of thermal energy delivery. While the problem of accurate needle positioning has been solved by stereotactic image-guidance and robotic solutions [4], the thermal energy delivery problem is still uncertain. Achieving a sufficient ablation margin is critical for local tumor control [5], but unnecessarily ablating large portions of healthy tissue. Specifically, achieving an ablation volume, customized to the tumor shape and an additional safety margin, remains a challenge.

***Corresponding author: Milica Bulatović:** ARTORG Center for Biomedical Engineering Research, University of Bern, Bern, Switzerland, e-mail: milica.bulatovic@artorg.unibe.ch
2nd Author Pascale Tinguely: Inselspital Bern University Hospital, Bern, Switzerland
3rd Author Stefan Weber, 4th Author Iwan Paolucci: ARTORG Center for Biomedical Engineering Research, University of Bern, Bern, Switzerland

Thus, to account for the stated need, we describe a novel approach for configuring ablation volumes and investigate its potential clinical application by creating custom ablation shapes in a technical phantom based on tumor shapes from real clinical cases.

2 Methods

To augment the process of conventional ablation where the volumes are overlapped manually, we aimed to regulate the ablation energy with respect to the needle position and depending on the target shape of the tumor. In such scenario, the output energy is monitored, and the needle is driven by a robot.

The experimental setup consisted of a thermal ablation system (Solero, AngioDynamics, USA), a surgical robot [6] and a tissue mimicking phantom [7] (Figure 1). The robot end effector was custom-built to hold the ablation needle in place. The phantom was a thermochromic polymer that changes colour when heated above necrosis-inducing temperatures (60°C) [8]. The ablation device and the robot were managed separately by the operator based on the status output from the robotic device.

In an effort to demonstrate clinical applicability of this concept, we searched for potential use cases that were considered fit for ablation (≤ 5 cm in diameter) and could benefit from non-spherical/ellipsoidal ablation shapes. We

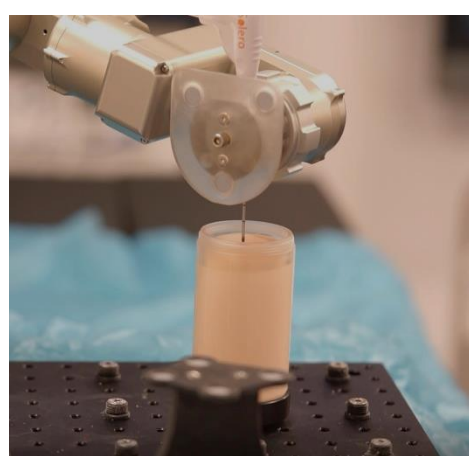

Figure 1 Display of the experimental setup. The ablation needle is attached to the robot arm. The phantom specimen is held in 2 dl containers.

selected four use cases from public datasets (3D-IRCADb, LiTS) and drafted corresponding ablation profiles consisting of ablation time, ablation power and needle position (Figure 2). The phantom samples were then ablated according to these profiles. After ablation, the phantom samples were cut along the needle axis to visualize and measure the ablation shape. The samples were measured using a custom software tool.

3 Results

Four representative cases were identified from the public datasets: (i) elongated tumor, (ii) irregularly shaped tumor, (ii) tumor adjacent to the skin, and (iv) tumor enclosing the portal vein.

We found that elongation of regular ablation volumes can be achieved by moving the needle with constant velocity and power throughout the trajectory (i). Increased velocity led to narrower ablations and increased power to wider ablations. Further, shape irregularities could be introduced by pauses in energy delivery between the segments (ii), whereas volume narrowing required decrease in power (iii). Lastly, superimposing multiple irregularly shaped volumes could create more complex shapes (iv).

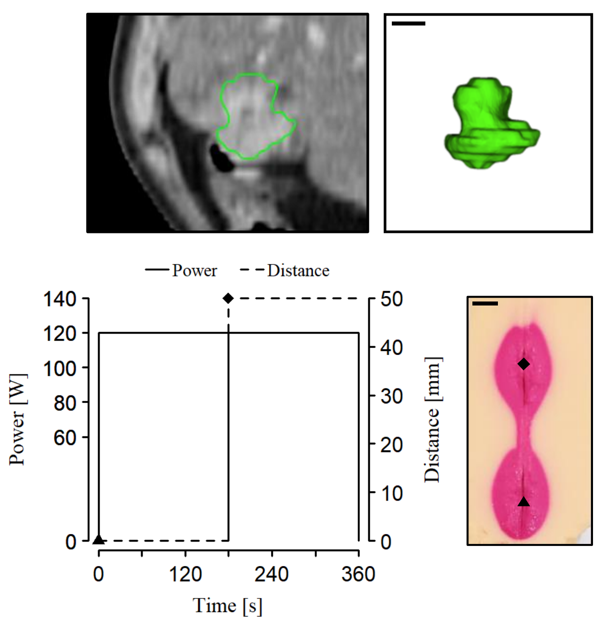

Figure 2 Example of a use case (top left) with its respective 3D reconstruction (top right), an ablation profile (bottom left) with the resulting volume in the phantom (bottom right). Corresponding (start and stop) points are marked in symbols (triangle and diamond). The scale bar measures 1 cm.

4 Discussion

Presently, we have employed our concept in a laboratory setting where we showed that the ablation volume could be customized discerning the tumor shape by using a robotic device. However, there were some limitations. The ablation device was controlled manually and lacked integration with the robot. Moreover, the phantom was homogenous, and the environment controlled so it did not depict real clinical scenarios. However, this setup allowed for a reproducible environment and consistent results and will set the base for future experiments.

In the future, we plan to address the mentioned shortcomings by integrating automated treatment planning, energy delivery fused with needle insertion, and quantitative treatment control.

5 Conclusion

To conclude, in this work we have demonstrated that the shape of the ablation volumes can be configured by modulation of ablation energy with reference to the needle position. We estimate that this methodology could be used to treat complex ablation cases with reproducible clinical results, ultimately thriving to treatment standardization.

Author Statement

Research funding: The authors state that the project was funded by Innosussie (37855.1 IP-LS). Conflict of interest: Authors state no conflict of interest. Informed consent: No human subjects were involved in this study. Images were obtained from public datasets.

References

[1] Nikfarjam M, Muralidharan V, Christophi C. Mechanisms of focal heat destruction of liver tumors. *Journal of Surgical Research*. 2005;127(2):208-223.

[2] Paolucci I, Sandu R-M, Tinguely P, et al. Stereotactic Image-Guidance for Ablation of Malignant Liver Tumors. www.intechopen.com

[3] Crocetti L, de Baére T, Pereira PL, Tarantino FP. CIRSE Standards of Practice on Thermal Ablation of Liver Tumours. *CardioVascular and Interventional Radiology*. 2020;43(7):951-962. doi:10.1007/s00270-020-02471-z

[4] Tinguely P, Frehner L, Lachenmayer A, et al. Stereotactic Image-Guided Microwave Ablation for Malignant Liver Tumors—A Multivariable Accuracy and Efficacy Analysis. *Frontiers in Oncology*. 2020;10(June). doi:10.3389/fonc.2020.00842

[5] Laimer, G., Schullian, P., Jaschke, N., Putzer, D., Eberle, G., Alzaga, A., Odisio, B. & Bale, R. Minimal ablative margin (MAM) assessment with image fusion: an independent predictor for local tumor progression in hepatocellular carcinoma after stereotactic radiofrequency ablation. *Eur. Radiol.* (2020). https://doi.org/10.1007/s00330-019-06609-7

[6] Weber S, Gavaghan K, Wimmer W, et al. Instrument flight to the inner ear. *Science Robotics*. 2017;2(4). doi:10.1126/scirobotics.aal4916

[7] Negussie AH, Partanen A, Mikhail AS, et al. Thermochromic tissue-mimicking phantom for optimisation of thermal tumour ablation. *International Journal of Hyperthermia*. 2016;32(3):239-243. doi:10.3109/02656736.2016.1145745

[8] Chu KF, Dupuy DE. Thermal ablation of tumours: Biological mechanisms and advances in therapy. *Nature Reviews Cancer*. 2014;14(3):199-208. doi:10.1038/nrc3672