Biomed Tech 2012; 57 (Suppl. 1) © 2012 by Walter de Gruyter · Berlin · Boston. DOI 10.1515/bmt-2012-4279

Transfer of methods from radiotherapy planning to ablation planning with focus on uncertainties and robustness

Markus Stoll[1], Thomas Boettger[1], Carsten Schulze[1], Mark Hastenteufel[1]

[1]Siemens AG, Healthcare Sector, Computed Tomography & Radiation Oncology, Heidelberg, Germany
Correspondence: markus.stoll@siemens.com, thomas.boettger@siemens.com, carsten.cs.schulze@siemens.com, mark.hastenteufel@siemens.com

Abstract

Recently, tumor ablation has been introduced as an additional modality in cancer treatment. Computer-based ablation planning is not yet established and could improve treatment outcome. Here a quite strong analogy to radiotherapy (RT) planning exists. Objective is to reuse and transfer computer-based methods from RT to ablation planning. Methods: An RT planning system is converted into an ablation planning system. The concept of robust planning, which is to determine the impact of uncertainty, is mapped to ablation planning. Results: A fully functional ablation planning prototype was implemented. The potential of robust planning could be demonstrated in an exemplary case using the new concept of probability-volume histograms (PVH). Conclusion: An ablation planning system based on an RT planning system confirms the close relation of RT and ablation planning. The new concept of robust ablation planning has been introduced.

1 Introduction

Recently, tumor ablation has been introduced as an additional modality in cancer treatment [1,2]. Using ablation needles, tumors are destroyed from inside by applying different physical principles, eg. radio-frequency, microwaves or lasers [1,3,4]. One has to ensure, to hit and fully destroy the tumor while avoiding critical structures on the needle path as well as in the vicinity of the malignant tissue (see **Image 1**). In clinical practice, ablation procedures are performed under image-guidance using C-Arms, CT or MRI [5,6] with mental planning only. Some computer-based ablation planning procedures which have the potential to improve treatment outcome, are described in literature [7,8,9,10,11] but are not yet clinically established. Ablation planning is focused on needle path planning [9,10] and/or calculation of the ablation zone (AZ) using either simple geometrical models [8] or sophisticated physical models [7,11]. Especially for navigated procedures planning becomes important or even mandatory [12].

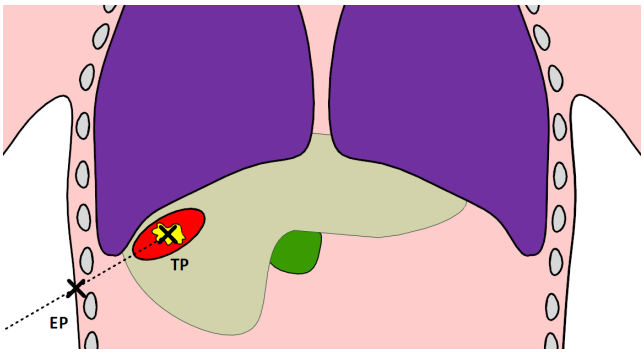

Image 1: Ablation with needle path (dotted line), entry point (EP), target point (TP), AZ (red) and tumor (yellow)

Looking at the main objectives of ablation planning, a quite strong analogy to radiotherapy (RT) planning seems obvious, where one aims to kill tumors by maximizing the dose to the tumor while minimizing dose to healthy tissue. Radiotherapy planning has evolved over the last decades from simple planning on Xray images, preprocedural simulation with dedicated simulation devices, virtual simulation using three-dimensional CT imaging to forward and inverse planning including dose calculation [13]. Latest developments in radiation therapy and radiotherapy planning include for example image-guided and adaptive therapy, inclusion of 4D data and robust planning [13, 14, 15]. Looking at the history of radiotherapy planning, one could question whether ablation planning is still in its early years and might evolve like radiotherapy planning.
In our group we have a long history with radiotherapy planning software: from virtual simulation (syngo® RT Dosimitrist) to inverse planning for photons (KonRad) and particles (syngo® RT planning). Objective of this work is a) to reuse and transfer computer-based methods from radiotherapy to ablation planning using existing software components and b) to implement a new method for robust ablation planning taking uncertainties into account.

2 Methods

In this work a forward planning system is developed, that provides a calculation of the AZ using Spheroids. The user defines an ablation plan and the system calculates the potential AZ to provide an evaluation of this plan. In ad-

dition the user can specify uncertainties, which will be taken into account for the evaluation.
The system allows the user to find robust plans by trying different setups and examining their impact on the ablation outcome.

2.1 Modeling an ablation

An ablation is modeled by one or more ablation instances. Each ablation instance can be specified by two sets of parameters: Geometrical parameters (skin entry point EP, target point TP) and the probe selection/configuration.
Based on this ablation plan a 3D scalar field which describes the AZ is calculated to allow the evaluation of the ablation plan. We use geometrical models, which are published by the manufactures of ablation probes, to calculate the AZ (see **Image 2**). Often Spheroids with a certain diameter and length are used. In this case the calculation is reduced to a unification of the spheroids of all ablation instances to one 3D binary AZ, which determines for each point in the patient if it is destroyed by the ablation. A more advanced approach is described in 2.3.

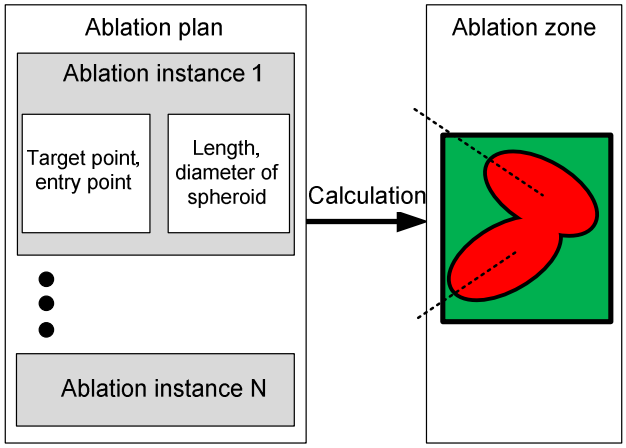

Image 2: Calculation of the AZ

2.2 Mapping to RT

In RT the patient is irradiated one or more times by radiation source(s) from different directions. Each irradiation is described by a so called RT beam during the planning process.
As each RT beam has a skin entry point and a target point (Isocenter), it can be reused to represent the geometric parameters of an ablation instance. This approach converts the RT plan to an ablation plan and allows the reuse of definition, storage and visualization features of a RT planning system for ablation plans.
The RT dose, a 3D scalar field describing the radiation dose for each point in the patient, is used to represent the AZ by replacing dose values with binary information.

2.3 Robust Planning

Uncertainties of needle positions and size of ablation areas affect the outcome of an ablation. This can be addressed by adding a safety-margin around the tumor (approx. 1 cm) to increase the probability of coverage for the actual volume by the AZ [16]. The size for the safety-margin does not take into account the actual uncertainties of the current case.
The drawbacks of the safety-margin approach are:

a) Healthy tissue is unnecessarily destroyed if the margin is defined very large.
b) The tumor volume is not entirely destroyed if the margin is defined very small.

The concept of robust RT planning, which is to determine the real impact of uncertainties, is transferred to ablation planning by using a probabilistic ablation zone (PAZ). It shows the probability of each point in the patient to be destroyed by the ablation (see **Image 3**). The PAZ is represented by an RT dose using values between 0 for 0% probability of destruction and 1 for 100% probability.

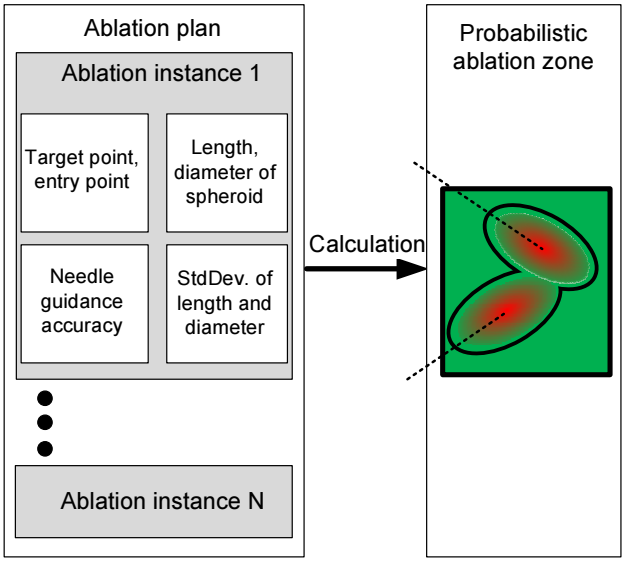

Image 3: Calculation of the PAZ

2.3 Probability-volume histogram

In RT planning, dose-volume histograms summarize the 3D dose into 2D graphs for tumor and organs at risk to allow the user a quick overview of the expected treatment result. This idea is transferred to robust ablation planning to summarize the 3D PAZ in a probability-volume histogram (PVH).

3 Results

A fully functional ablation planning prototype was implemented based on the syngo® RT planning software.

3.1 Reuse of RT Planning

The user can create an ablation plan and add ablation instances. The software supports the user in finding proper needle entries and target points by displaying the needle path with projections on 2D MPR images, in 3D renderings (see **Image 4**) and a so-called needles eye view. The AZ is visualized in 2D image slices and allows checking

the coverage of tumor and organs at risk (see **Image 5**). Plan review and comparison tools can be used to display differences of ablation plans or display the same plan on multi-modality images like CTs, MRI or PETs.

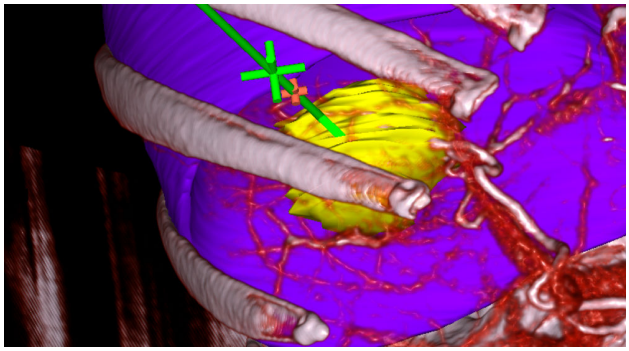

Image 4: 3D rendering of an ablation

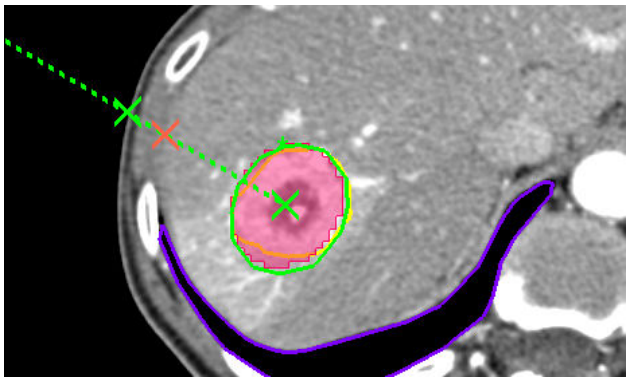

Image 5: Needle path and binary ablation zone of an ablation instance

3.2 Probabilistic ablation zone

The PAZ reveals areas of the tumor with a low probability of being destructed by the ablation. The user can increase the expected treatment result by changing parameters of existing ablation instances or adding more instances. **Image** 6 shows the PAZ of an ablation plan including two instances modeled by spheroids with a length of 65±11 mm and a diameter of 53±6 mm. The accuracy of the guiding system is 5 mm (standard deviation).

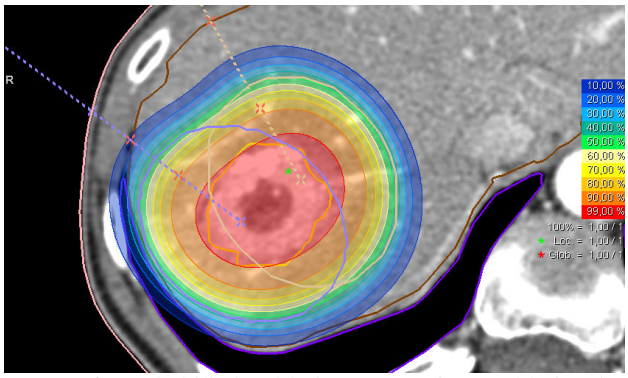

Image 6: Probabilistic ablation zone of two ablation instances

3.3 Probability-volume histogram

The coverage of a tumor or organs at risk is described by curves in the PVH. Each curve shows the probability of destruction vs. the relative volume portion in percentage. In **Image 7,** two ablation plans are compared using the PVH. The ablation plan with two instances of micro wave ablations (2xMWA) shows a good coverage of the tumor: more than 97% of the tumor is destroyed with a probability of 95%. The ablation plan with one instance of a micro wave ablation (1xMWA) shows a lower coverage of the tumor: only more than 94% of the tumor is destroyed with a probability of 95%.

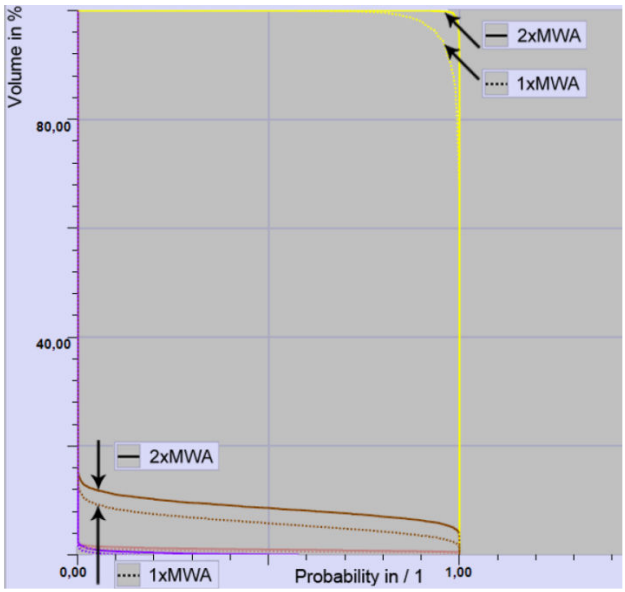

Image 7: PVH showing two ablation plans with tumor (yellow), lung (pink) and liver (brown)

4 Conclusion

4.1 Reuse of RT Planning

The fast implementation of the ablation planning system based on an RT planning system confirms the close relation of RT and ablation planning. Similar work to ours is described by Trovata et al. [8], where a dedicated ablation planning plug-in for an RT planning system is described.

4.2 Robust Planning

The new concept of robust ablation planning has been introduced. It gives a quantitative method to take user-defined uncertainties into account by providing two evaluation tools: the PAZ and the PVH

- The PAZ allows to find a) areas of the tumor, that are not covered by the ablation with sufficient probability (see **Image 8**) and b) organs at risk, which are covered with a too high probability.

- The PVH allows comparing ablation plans summarized in a single diagram to make a fast evaluation of different plans possible.

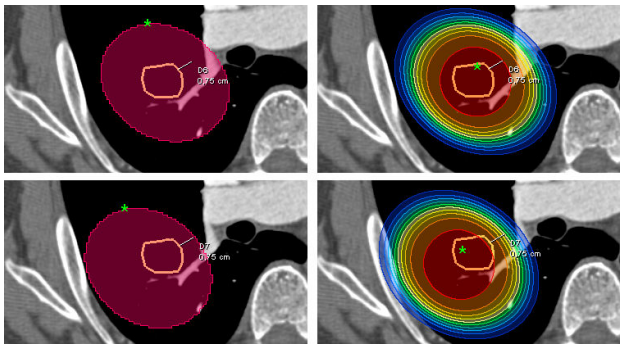

Image 8: Binary vs. probabilistic ablation zone

These tools allow finding a robust plan based on actual uncertainties of the current case. The robust planning approach can help to circumvent the drawbacks associated with the safety-margin approach described in 2.3. In a next step, the benefit of robust ablation planning should be evaluated in clinical studies.

5 References

[1] Künzli BM, Abitabile P, Maurer CA, Radiofrequency ablation of liver tumors: Actual limitations and potential solutions in the future, World J Hepatol 2011; 3(1): 8-14

[2] Mahnken AH, Bruners P, Guenther RW, Techniques of Interventional Tumor Therapy (in German), Dtsch Arztebl 2008; 105(38): 646–53

[3] Haigron P, Dillenseger J-L, Luo L, Coatrieux J-L, Image-guided therapy: evolution and breakthrough, IEEE Eng Med Biol Mag. 2010; 29(1): 100–104

[4] O´Rourke AP, Haemmerich D, Prakash P, Converse MC, Mahvi DM, Webster JG, Current status of liver tumor ablation devices, Expert Rev. Med. Devices 2007; 4(4): 523-537

[5] Wood BJ, Locklin JK, Viswanathan A, Kruecker J, Haemmerich D, Cebral J, Sofer A, Cheng R, McCreedy E, Cleary K, McAuliffe MJ, Glossop N, Yanof J, Technologies for Guidance of Radiofrequency Ablation in the Multimodality Interventional Suite of the Future, J Vasc Interv Radiol 2007; 18:9–24

[6] Orth RC, Wallace MJ, Kuo MD, C-arm Cone-beam CT: General Principles and Technical Considerations for Use in Interventional Radiology, J Vasc Interv Radiol 2008; 19:814–821

[7] In vivo validation of a therapy planning system for laser-induced thermotherapy (LITT) of liver malignancies Lehmann KS, Frericks BB, Holmer C, Schenk A, Weihusen A, Knappe V, Zurbuchen U, Peitgen HO, Buhr HJ, Ritz JP, Int J Colorectal Dis 2011; 26:799–808

[8] Trovata K, Dalal S, Kruecker J, Venkatesan A, Wood BJ , Automated RFA planning system for complete coverage of large tumors, Proc. of SPIE Vol. 7261, 2009, p. 72610D-1 (7pp.)

[9] Fast Automatic Path Proposal Computation for Hepatic Needle Placement, Schumann C, Bieberstein J, Trumm C, Schmidt D, Bruners P, Niethammer M, Homann RT, Mahnken AH, Pereira PL, Peitgen HO, Proceedings of the SPIE, Vol.7625, 2010, p.76251J (10 pp.)

[10] Seitel A, Engel M, Sommer CM, Radeleff BA, Essert-Villard C, Baegert C, Fangerau M, Fritzsche KH, Yung K, Meinzer HP, Maier-Hein L, Computer-assisted trajectory planning for percutaneous needle insertions, Med.Phys. 2011; 38(6): 3246-3259

[11] Optimizing Electrode Placement Using Finite-Element Models in Radiofrequency Ablation Treatment Planning
Chen CCR, Miga MI, Galloway Jr. RL IEEE Trans. Biomed. Eng. 2009; 56(2): 237-245

[12] Stereotaxy: Breaking the limits of current radiofrequency ablation techniques, Bale R, Widmann G, Stoffner DIR, European Journal of Radiology 2010; 75: 32–36

[13] Schlegel W, Bortfeld T, Grosu AL (Eds.), New Technologies in Radiation Oncology, Springer, 2006

[14] Liu W, Zhang X, Li Y, Mohan R, Robust optimization of intensity modulated proton therapy, Med. Phys. 2012; 39(2): 1079-1091

[15] Bert C, Durante M, Motion in radiotherapy: particle therapy, Phys. Med. Biol. 2011; 56:R113–R144

[16] Rieder C, Weihusen A, Schumann C, Zidowitz S, Peitgen HO, Visual Support for Interactive Post-Interventional Assessment of Radiofrequency Ablation Therapy, Computer graphics forum 2012; 29: 1093–1102