References

[1] Sahgal A, Ma L, Gibbs I, Gerszten PC, Ryu S, Soltys S, Weinberg V, Wong S, Chang E, Fowler J, Larson DA (2010) Spinal cord tolerance for stereotactic body radiotherapy. Int. J Radiat. Oncol. Biol. Phys. 77(2):548–553.

[2] Fowler JF (1989) The linear-quadratic formula and progress in fractionated radiotherapy. Br J Radiol 62(740):679–694.

Integration of DICOM-RT into instrument guidance system for intra-operative interstitial HDR-brachytherapy

G. Toporek[1], D. Wallach[1], M. Peterhans[1], J. Vock[2], D. Terribilini[3], M. K Fix[3], P. Manser[3], D. M Aebersold[2], S. Weber[1]

[1]University of Bern, Artorg Center for Computer Aided Surgery, Bern, Switzerland

[2]Inselspital, Bern University Hospital, Department of Radiation Oncology, Bern, Switzerland

[3]Inselspital, Bern University Hospital, Division of Medical Radiation Physics, Bern, Switzerland

Keywords Image-guided radiation therapy · Brachytherapy · Intra-operative · DICOM-RT

Purpose

Intra-operative interstitial high-dose-rate brachytherapy (HDR-IOBT) has the potential to gain the importance as an integrated approach to the complex, multidisciplinary treatment of advanced cancer. This novel technique may eliminate the time interval between surgery and radiotherapy, thus the risk of possible tumour recurrence could be reduced.

An accuracy of the radiation source placement has a great impact on the delivered radiation dose. To date, it is up to the skills and experience of radiation oncologist to apply pre-operative findings during the brachytherapy intervention. However, in many cases an iterative repositioning of catheters is required causing excess of a prescribed intervention time. Thus, the main challenge in HDR-IOBT is to precisely apply the treatment plan to the patient and facilitate image-guided implantation of the applicator according to it. However, different medical formats, specific for particular treatment planning software (TPS) and lack of both clear communication standards and robust surface reconstruction methods from cloud of unstructured points are the main deficits in this field.

We propose a stereotactic instrument guidance system that allows accurate placement of the catheter according to the pre-interventional information. For this purpose, a treatment plan is transferred and reconstructed at a navigation system from a DICOM-RT medical format that is available from most of the TPS.

Methods

A surgical navigation system developed for microwave ablation and open liver surgery [1] was extended to fulfill the requirements of HDR-IOBT. The original system uses optical tracking (NDI Vicra, Northern Digital, Canada), intra-operative 2D ultrasound (Terason T3000, Teratech, USA) and a set of custom tools to allow precise patient-to-image registration and accurate placement of the needle into the target tumour (i.e. microwave ablation applicator, Accu5i, Microsulis, UK).

In order to adapt this system to the use of HDR-IOBT, an interface was added to display the radiation treatment plan, transferred from the planning system using the DICOM-RT medical data format. According to this format, contours of organs at risk (OARs), target volumes (GTV, CTV and PTV), planned catheter's trajectories and radiation source positions are encoded as unstructured point clouds while the planned dose distribution computed by the TPS is encoded as a grayscale 3D image.

To be visualized in the developed interface, surfaces of the OARs and target volumes were reconstructed by using a method presented in [2] followed by the marching cubes algorithm [3]. The method consists of three stages: definition of the function that approximates the signed geometric distance to the unknown surface, sampling of the function on the regular grid and contouring at zero using the marching cubes algorithm.

Transfer of the catheter's trajectories from the DICOM-RT file was straightforward, as they were reconstructed from the given source positions and imported into navigation system as entry and target point for the needle. The transfer of the dose distribution was similarly straightforward, as the scalar volume could be rescaled and directly imported in the navigation system. All these structures were then superimposed on an available image data set (CT, MRI, MeVis).

The accuracy of the surface reconstruction of the OARs and the target volumes was studied on one data set from a patient that could be treated by HDR-IOBT. A first, qualitative evaluation was made by visually comparing the reconstructed surface with the surfaces defined in the TPS. A quantitative evaluation was then performed by computing the reconstruction error as the distance between the center of every cell in the reconstructed surface and the closest 3D point in the original point cloud. The mean and standard deviation of this reconstruction error were computed for the target volumes and the OARs.

The feasibility of needle guidance according to the treatment plan has been evaluated on the rapid prototyped models of the liver (Fig. 1). A virtual scene from the navigation system, equipped with crosshair viewer, allowed a precise adjustment of the needle tip and shaft.

Results

A comparison between the reconstructed surfaces of OARs and the ground truth (defined in the TPS) is depicted in Fig. 2a, b. Figure 2c represents a color map of the reconstruction error for the target

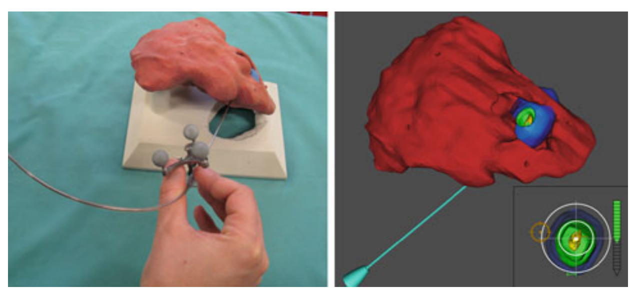

Fig. 1 An insertion of a plastic catheter attached to the rigid needle into the rapid prototyped model of the liver (*left*), which is guided by the navigation system according to the virtual treatment plan (*right*)

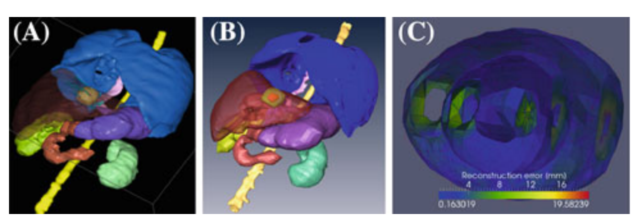

Fig. 2 Comparison of OARs and target volumes in treatment planning software (**a**) and the proposed surface reconstruction method (**b**) from unstructured point clouds. **c** Depicts *color map* of the reconstruction error of the target volumes (GTV, CTV and PTV). High error at the sides of the structures is caused by the lack of available points

Table 1 Mean and standard deviation of the reconstruction error in mm for the gross target volume (GTV), the clinical target volume (CTV), the planned target volume (PTV), the organs at risk (OAR) and the overall error

	Structure	Average reconstruction error [mm]
Target volumes	GTV	1.50 ± 0.97
	CTV	1.41 ± 0.94
	PTV	1.42 ± 0.78
OARs	Kidneys	0.79 ± 0.46
	Stomach	1.46 ± 0.84
	Liver	1.70 ± 1.01
	Overall	1.40 ± 0.32

volumes (GTV, CTV and PTV). Errors for different structures, summarized in Table 1, show that 3D surface models of the structures (target volumes and OARs) were reconstructed from the information available in the DICOM-RT with an overall average error of 1.40 ± 0.32 mm, representing 97 % of the CT pixel size (axial plane). When taking into account that arbitrary margin added to the GTV is usually set to 6 mm, such a reconstruction error might be negligible.

Conclusion

In this work, the feasibility of image-guided applicator implantation according to the treatment plan for intra-operative HDR-brachytherapy was proved. An instrument guidance system for open liver surgery has been successfully adapted to HDR-IOBT treatments of the liver. The transfer of the radiotherapy treatment plan into the navigation system was observed with a mean error of 1.40 ± 0.32 for OARs and target volumes, while no precision lost was achieved for catheters' trajectories and isodose curves. In the future, such guidance technology will increase the precision in the positioning of the radiation sources within the patient's body. Future work will be dedicated to the evaluation of the system's workflow in ex vivo and in vivo experiments.

References

[1] Peterhans M., Weber S. (2010) A navigation system for open liver surgery: design, workflow and first clinical applications. International Journal of Medical Robotics and Computer Assisted Surgery, 7: 7–16.

[2] Hoppe H. (1994) Surface Reconstruction from Unorganized Points. Ph.D. Thesis, Computer Science and Engineering, University of Washington.

[3] Lorensen WE., Cline HE. (1987) Marching Cubes: A high resolution 3D surface construction algorithm, Computer Graphics, 21: 163–169.

Automatic segmentation of the heart LV from cardiac MR images using a 3D nonlinear statistical shape model

S. Faghih Roohi[1], R. A. Zoroofi[1]

[1]University of Tehran, School of Electrical and Computer Engineering, Tehran, Iran

Keywords Active shape model · Active appearance model · Statistical shape modelling · Kernel PCA

Purpose

In this paper, we propose a method for 3D automatic segmentation of the heart LV using a 3D nonlinear statistical shape model. The nonlinear distribution of the landmarks is modelled by Kernel PCA. In the training stage, a PCA-based active appearance model and a KPCA-based active shape model are constructed. The 3D AAM is fitted on short-axis MR data to obtain an initial segmentation surface. The accurate segmentation is achieved by applying the KPCA-based 3D ASM to the initial surface. The method's performance is assessed by comparison with manually segmented datasets. The results show that our method improves segmentation accuracy comparing with the combination of PCA-based AAM and ASM.

Methods

The proposed method is divided into two major parts:

1. A statistical shape model is built for the inner and outer wall of the heart LV at specific phase of a cardiac cycle.
2. The constructed statistical shape model is utilized as priori knowledge for cardiac LV segmentation.

The statistical modelling of shape and appearance is composed of the following steps:

1. The method proposed by Frangi et al. is used to build an initial atlas from the training samples, extract pseudo-landmark of the atlas using Marching Cubes algorithm and propagate landmarks back to the surface of the training samples using FFD non-rigid registration.
2. The nonlinear variation of the landmarks is modelled by a Kernel PCA (KPCA)-based active shape model (ASM). To achieve this, KPCA is utilized instead of PCA in the conventional ASM. The important thing in applying KPCA for statistical modelling is how to constrain the model parameters according to the utilized kernel function. We exploit the pseudo-density function which was defined by Davies et al. to attain the acceptable shape for statistical shape modelling.
3. A PCA-based active appearance model (AAM) is constructed to model the distribution of the image intensity.

The segmentation procedure using constructed ASM and AAM is composed of the following steps:

1. The AAM is applied to the test datasets to find the epicardial and endocardial surfaces of the LV. The extracted surfaces are utilized as an initial segmentation result for the next step.
2. The KPCA-based ASM is utilized to modify the initial surfaces of the LV and find the accurate segmentations. The segmented shapes are modified to generate shapes similar to those in the original training set in each iteration. Besides, an approximate pre-image should be reconstructed in each iteration of applying ASM. We utilize a simple algebraic method proposed by Rathi et al. to estimate the pre-image.

The whole modelling and segmentation procedure is summarized in Fig. 1.

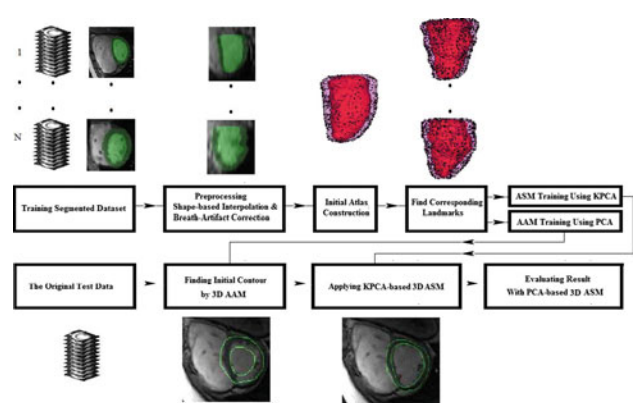

Fig. 1 The *block diagram* of the proposed statistical shape modelling and image segmentation method