

Organ Contour Adaptor to create new structures to use for adaptive radiotherapy of cervix cancer using Matlab Bridge and 3DSlicer / SlicerRT

Y. Seppenwoolde^{1,2}, M. Daniel², H. Furtado^{2,3}, D. Georg^{1,2}

¹ Christian Doppler Laboratory for Medical Radiation Research for Radiation Oncology, Medical University Vienna, Austria

² Department of Radiation Oncology, Medical University Vienna, Austria

³ Center for Medical Physics and Biomedical Engineering, Medical University Vienna, Austria

Abstract. In commercially available clinical radiotherapy software there is no turn-key solution for adaptive radiotherapy. For example the applications that are designed for organ contouring and treatment plan optimization do not provide solutions to generate new contours based on a (non-rigid) organ motion model. To interpolate linearly between two extreme positions and/or filling states of patient's organ contours, a MATLAB-based tool was integrated into 3DSlicer / SlicerRT using the Matlab Bridge, allowing generation of intermediate uterus as well as bladder contours that are used for treatment plan optimization in adaptive radiotherapy of cervix cancer.

Keywords: Adaptive radiotherapy, workflow automation, Slicer, Matlab.

1 Introduction

For patients with cervical cancer, despite the increased accuracy of irradiation techniques, sparing of bladder, rectum and small bowel is still challenging because all organs at risk (OAR) in the pelvic area change shape and position on a daily basis due to variations in filling (Fig. 1). With the introduction of cone-beam CT scanners that are mounted directly at the linear accelerator, it became possible to observe these changes of internal organ configurations of patients during each treatment fraction. Theoretically, this enables re-adaptation of plans according to tumour shrinkage and changes in OAR morphology, resulting in reduction of toxicity [1,2]. Full online plan adaptation requires that re-delineation, re-optimizing of dose distributions and repetition of all legally required quality assurance steps should be performed in a few minutes. These workload intensive procedures would require a high degree of automation and workflow-integration that is currently absent in off-the-shelf products.

Nonetheless, by finding a well-balanced compromise between full automation and degree of plan adaptation, it is possible to apply a simplified scheme of adaptation that provides improved treatment.

Based on our own experience and that of other research groups [3], patients can be divided into two groups: the first group consists of patients who show uterus motion as a function of bladder filling (called “Movers”) and the second group are those patients whose uterus position stays relatively stable regardless of bladder volume (“Non-Movers”). With a model for the uterus position, a pre-determined set of plans for can be constructed for the “Movers” and the most appropriate treatment plan can be selected on a daily basis, while for the “Non-Movers” a single plan will suffice (See Fig. 2).

Although an empty bladder might be more reproducible and easy to obtain for the patients, it is favourable for the patient to have a full bladder because it pushes the bowel out of the high dose area. In addition, a full bladder will increase the distance of the ventral bladder wall to the high dose area. Patients are routinely instructed to have a full bladder at the time of treatment by means of a standardized drinking protocol. This in order to ensure that we are able to irradiate the largest portion of fractions with the half full to full library plan before it starts to get difficult for the patient to maintain a full bladder due to the early bladder radiation response (irritation, onset of inflammation).

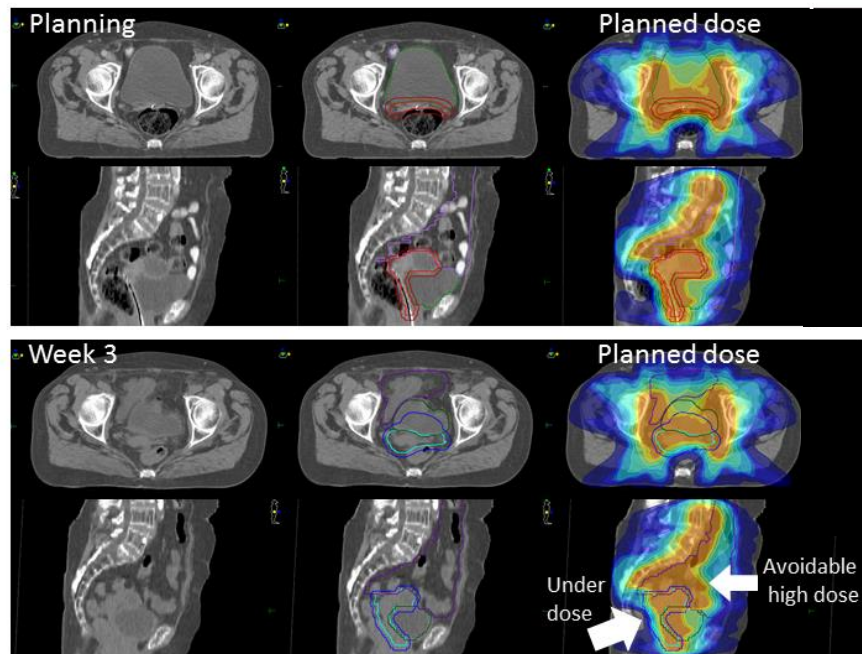


Fig. 1. Example of changing organ positions between planning and 3rd week of treatment.

The patients are asked to empty their bladder after treatment and the weight of the patient is assessed before and after this micturition to provide immediate feedback about their bladder volume and the effectiveness of the drinking protocol. However, despite these measures, bladder filling is hard to manage on an individual basis.

The patient specific relation between bladder filling and the position of the uterus can be assessed by making a set of CT scans with full and empty bladder. A two stage approach, consisting of two treatment plans, one for an empty to half full and one for half full to full bladder, has been shown to give a good level of plan adaptiveness [2], ensuring both a good tumor coverage as sparing of the surrounding healthy tissue.

Commercially available clinical software that is designed for organ contouring and treatment plan optimization does not provide solutions to generate new contours based on a motion model that interpolates between two extreme (filling) positions of an organ.

We developed a MATLAB-based tool that allows generating intermediate contours of uterus as well as bladder, according to the available bladder volumes. Its main purpose was to interpolate linearly between two extreme positions and/or filling states of patient's organ contours. Non-rigid deformation between one organ position and the other is made by matching the outer contour of both structures. To facilitate data handling and DICOM import/export options, the Matlab code is integrated to 3DSlicer / SlicerRT [4,5] by using the MatlabBridge.

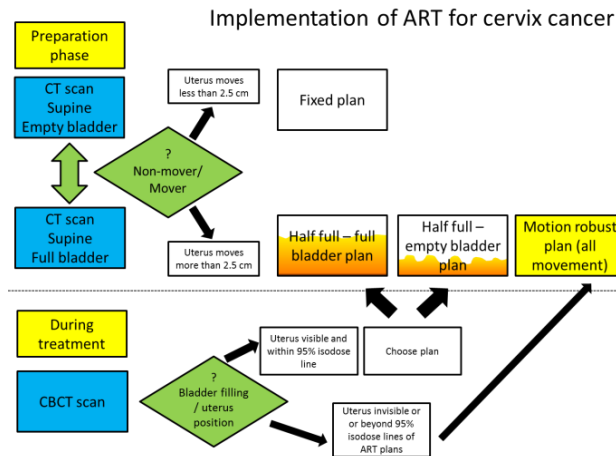


Fig. 2. Clinical workflow.

2 Materials and Methods

MatlabBridge is an extension of 3DSlicer / SlicerRT to allow running Matlab functions directly in 3D Slicer: it takes the input from the data loaded into 3DSlicer / SlicerRT, processes the Matlab routine inclusive user interaction and transfers the pro-

cessed data back to Slicer allowing visualization of the results in Slicer right after the execution is completed.

The Matlab code to interpolate contours has been developed in-house, but the generated contours could not directly be read by the treatment planning system. Loading them into 3DSlicer / SlicerRT and saving the contours solved this problem. To avoid unnecessary and time-consuming data transfer between the two programs, Matlab-Bridge was used to connect them. Furthermore, all 3DSlicer / SlicerRT's built-in image processing features could be used, without having to program them into Matlab, and on the other hand also all Matlab functionality can be used unlimited. The registration of empty and full organ structures was based on the continuous point drift code package (CPD2) [6]. CPD2 simultaneously finds both the non-rigid transformation and the correspondence between two point sets without making any prior assumption of the transformation model except that of motion coherence. This method can estimate complex non-linear non-rigid transformations, and is shown to be accurate on 2D and 3D examples and robust in the presence of outliers and missing points. For our specific purpose, an interpolated half full contour was created by using an interpolation factor (Fig. 2) that could be automatically calculated based on detected bladder volumes, or could be user defined. The interpolation factor depends on the bladder filling as measured in the available full and empty bladder CT scans and does not necessarily have to be 50% because sometimes a considerable remaining volume is present in the empty bladder scan, or the bladder in the full bladder scan is not completely full (as often can be estimated based on the patient anatomy as appearing in the scans). In case one of the two CT scans of the patient has a too small full bladder contour, or a too large empty bladder contour, extrapolated contours can be created as well (to some extent and with sanity check of the results). This reduces the need for the patient to be rescanned and reduces patient radiation exposure. The (extra-) interpolated contours were added to an existing DICOM file and transferred to the commercial treatment planning system (Monaco, Elekta AB, Stockholm, Sweden). Connectivity to other planning systems can be easily added.

3 Results

For adaptive radiotherapy for patients with Cervix cancer, a two stage approach, consisting of two treatment plans, one for an empty to half full and one for half full to full bladder was found to increase target coverage (Table 1). For the creation of an intermediately filled bladder contour and the corresponding intermediate uterus contours out of two CT scans with full and empty bladder, the new software was used.

Some results and the integration of the in-house developed Matlab code into 3DSlicer / SlicerRT is shown in Fig. 3. Newly generated contours can be checked directly after creation using the corresponding CT images in the 3DSlicer / SlicerRT user interface before they are exported to the clinical treatment planning system. The whole procedure takes between 30 and 45 minutes. With the newly created structures we were able to create two different treatment plans (Fig. 4). With daily CBCT scans that are made just before the treatment starts with the patients at the treatment table of the

linear accelerator, the current position of bladder and uterus can be determined and the most appropriate dose distribution can be chosen. The procedure was tested for 3 patients and a “sanity” check on the produced contours was performed by comparing the generated intermediate structures by CBCT scans that had similar bladder volumes. All intermediate structures created by the system were considered to be anatomically logical with a clinically relevant level of accuracy. The effect of the new structures on the dose distributions is shown in Table 1. Especially for the Mover patient (P3, Fig. 4), the target coverage increased a lot, by the cost of higher dose to the bladder. For the non-Mover patients the differences are smaller, although for P1 the dose to the bowelbag decreased significantly due to ART.

		Target		Bladder		Rectum		Bowelbag	
		V<42.75(%)		V30 (%)		V30 (cc)		V30 (cc)	
		average	SD	average	SD	average	SD	average	SD
P1	Clinical	8	5	52	9	85	21	601	180
	ART combi	4	4	53	9	71	20	393	183
P2	Clinical	0	0	75	4	30	10	392	75
	ART combi	0	1	79	5	27	9	346	75
P3	Clinical	22	15	49	4	53	24	447	148
	ART combi	1	3	86	15	53	25	447	139

Table 1. Dose-volume parameters for radiotherapy treatment plans that were made using the newly created structures, compared to the clinical plan that was based only on the planning-CT scan. For the target, the relative volume that received less than the prescribed dose of 42.75 Gy was calculated, for the OARs, the relative (bladder) or absolute (rectum and bowelbag) volume that received more than 30 Gy was calculated. P1 and P2 were non-movers, P3 was a mover. The average values were determined by evaluating the planned dose distributions for contours obtained from daily CBCT scans.

4 Conclusions

For adaptive radiotherapy for patients with Cervix cancer, a two stage approach, consisting of two treatment plans, one for an empty to half full and one for half full to full bladder will be implemented soon in our clinic. 3DSlicer’s MatlabBridge enabled us to integrate in-house developed Matlab code in a way so that the image viewing features and DICOM in- and export routines of SlicerRT could be used, combined with the more flexible programming options regarding contour deformation of Matlab. Especially the reviewing option for the newly created contours provided us with an extra safety step before importing the generated contours directly into the clinical planning system.

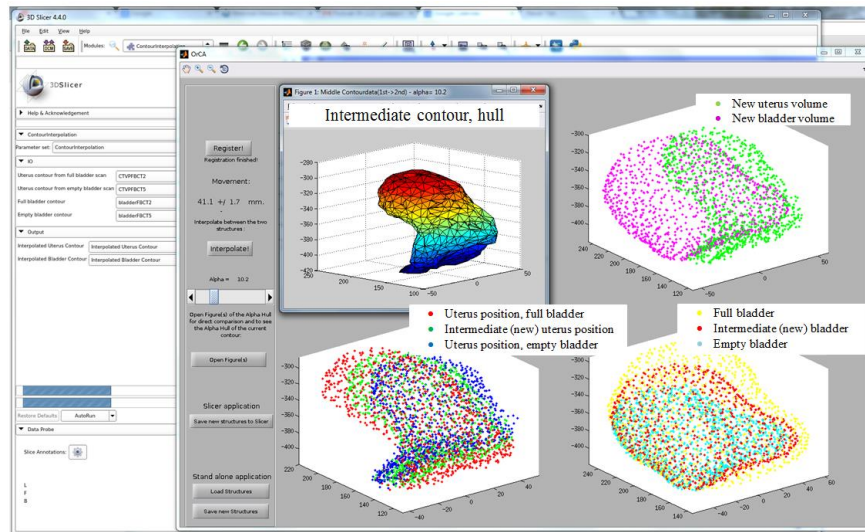


Fig. 3. Screenshot of the user-interface of 3DSlicer / SlicerRT and Matlab screens. Point clouds of input uterus and bladder contours and interpolated middle uterus and bladder contour are shown. New slices are determined by the triangulated surfaces. DICOM export is done using 3DSlicer / SlicerRT modules and user interface.

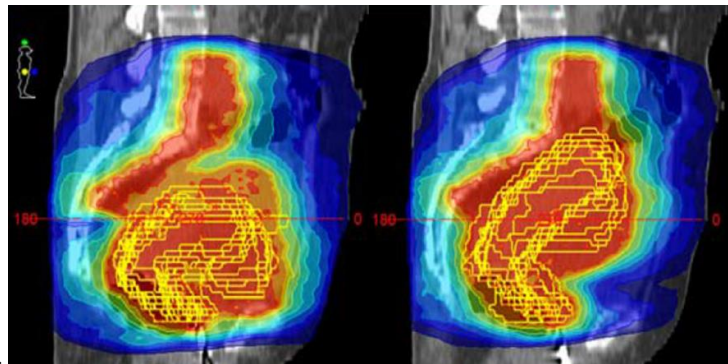


Fig. 4. Example of two optimized dose distributions (color wash) for the motion model of the uterus for empty to half-full (left panel) and half-full to full (right panel) bladder. The corresponding uterus positions as measured by the daily CBCT (yellow) for all treatment fractions of one patient are overlaid.

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