Target point correction optimized based on the dose distribution of each fraction in daily IGRT

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Abstract. Purpose: To use daily re-calculated dose distributions for optimization of target point corrections (TPCs) in image guided radiation therapy (IGRT). This aims to adapt fractioned intensity modulated radiation therapy (IMRT) to changes in the dose distribution induced by anatomical changes. Methods: Daily control images from an in-room on-rail spiral CT-Scanner of three head-and-neck cancer patients were analyzed. The dose distribution was re-calculated on each control CT after an initial TPC, found by a rigid image registration method. The clinical target volumes (CTVs) were transformed from the planning CT to the rigidly aligned control CTs using a deformable image registration method. If at least 95\% of each transformed CTV was covered by the initially planned D95 value, the TPC was considered acceptable. Otherwise the TPC was iteratively altered to maximize the dose coverage of the CTVs. Results: In 14 (out of 59) fractions the criterion was already fulfilled after the initial TPC. In 10 fractions the TPC can be optimized to fulfill the coverage criterion. In 31 fractions the coverage can be increased but the criterion is not fulfilled. In another 4 fractions the coverage cannot be increased by the TPC optimization. Conclusions: The dose coverage criterion allows selection of patients who would benefit from replanning. Using the criterion to include daily re-calculated dose distributions in the TPC reduces the replanning rate in the analysed three patients from 76\% to 59\% compared to the rigid image registration TPC.

1. Introduction
Patient positioning during treatment delivery of fractioned IMRT can be realized by a stereotactic setup. Uncertainties in this setup and anatomical changes, caused by different organ filling levels, tumor shrinkage or weight loss, make an additional correction of the patient position necessary. This can be realized by an additional table shift to change the target point – a target point correction (TPC).

In image guided radiation therapy (IGRT) a control CT scan can be used to calculate a TPC with image based methods like rigid image registration in the tumor region. Anatomical changes can be taken into account by using deformable image registration approaches \cite{1}. The effects of anatomical changes to the dose distribution are still a matter of current research. In this work we extend the image-derived TPC calculation by incorporating the dosimetric changes.
2. Methods and Material

We use a deformable image registration to propagate the volumes of interest (VOIs) from planning CT to control CT (see Figure 1), which is acquired with an in-room on-rail spiral CT. The dose is recalculated on the control CT and a TPC is calculated to maximize dose coverage of the propagated clinical target volumes (CTVs).

We evaluate our dosimetric TPC calculation method by comparing its results to a TPC calculated with rigid image registration based on mutual information in a retrospective study.

2.1. Patients

Three head-and-neck cancer patients, who received postoperative IMRT in 28-32 fractions, were included in the retrospective study. 68 daily images (30 of patient 1, 30 of patient 2 and 8 of patient 3) acquired with an in-room on-rail spiral CT-Scanner were available and enabled dosimetric TPC calculations. All patients had a customized fixation device, which was used for patient immobilization and stereotactic setup.

2.2. IMRT plans

Two CTVs (CTV1, CTV2) were defined for each patient. A dose of 70.4 Gy was prescribed to the CTV1, which contains only the gross tumor region. The CTV2, where a dose of 57.6 Gy was prescribed, includes the cervical and supraclavicular lymph nodes. The CTV2 was split into three parts (see Figure 1, top-left) to allow separated coverage analyses of the three partial volumes, which have different deformability. A 3.0 mm CTV-to-PTV margin was applied. The maximum dose for the spinal cord was limited to 40 Gy.

2.3. TPC optimization

The optimization of the TPC is performed in four steps (see Figure 2). Steps 2-4 are repeated until an acceptable coverage was found or a maximum number of iterations was reached.

2.3.1. Registration and VOI propagation

The control CT is rigidly aligned to the planning CT using stereotaxy. A displacement vector field is calculated using a fully automated deformable image registration method to propagate the contours of

Figure 1: CTVs in planning-CT (top-left) are transformed to the control CT (top-right) using an elastic image registration method. If the dose distribution of the planning CT (shown on CTV surfaces bottom-left) is recalculated on the control CT, under-dosage may occur (shown as blue areas on the transformed VOI surfaces bottom-right).
all CTVs from the planning CT to the control CT [2]. The propagated contours are reviewed by a radiation oncologist to exclude fractions with registration errors.

2.3.2. Dose re-calculation on control CT after TPC
The target point of the plan is modified according to the TPC vector and the dose distribution is re-calculated on the control CT. In the first iteration the TPC vector is initialized using rigid image registration. The result of the coverage optimization is used in the following iterations.

2.3.3. Dose coverage calculation
The D95 values of the PTVs are extracted from the DVHs of the initial plan and used as a threshold dose value for the corresponding CTV. Coverage for each CTV of more than 95% was chosen as acceptance criterion. If this criterion is fulfilled or a maximum number of iterations is reached, the optimization is stopped.

The coverage is calculated using a mask for each CTV marking the dose region having dose values above the corresponding threshold. The overlap of each region with the corresponding voxel grid mask of the VOI, normalized by the total volume of the VOI, is the coverage.

2.3.4. Coverage optimization
A simplex optimizer alters the TPC translation vector to reach coverage of 95% or more for all CTVs. During this step the dose distribution is assumed to be invariant in respect to the TPC. Thus the dose distribution is re-calculated in the next step (2.3.2) to allow an exact calculation of the coverage.

Figure 2 optimization workflow: The VOIs are propagated using a deformable image registration, the dose is re-calculated on the control CT, areas having dose values above CTV specific threshold are extracted to calculate the coverage and the coverage is optimized by altering the TPC vector.
3. Results

59 out of 68 fractions of all three patients passed the review of the propagated contours. In 24% (14 out of 59) of these fractions the coverage criterion was already fulfilled after the initial image based TPC without any coverage optimization steps. In 17% of these fractions (10 out of 59) the TPC was successfully optimized to fulfill the coverage criterion. In 53% of these fractions (31 out of 59) the coverage could be increased but the criterion could not be fulfilled after of 10 iterations. In 7% of these fractions (4 out of 59) the coverage could not be increased by the TPC optimization. Figure 3 shows the volumes having a lower dose value than the corresponding dose threshold. The 5% tolerance of the coverage criterion was subtracted.

To conform to the initially planned dose distribution a new plan optimization is needed. Our method supplies an objective measure to select candidates for replanning.

![Example: Dose coverage of Patient 1](chart.png)

**Figure 3: Volume outside corresponding dose threshold for all CTVs**

4. Conclusions

The proposed dose coverage criterion can help to identify fractions with under-dosages, in which case replanning is suggested. Using the criterion to optimize the TPC reduces the replanning rate in the analyzed three patients from 76% to 59% compared to the rigid image registration TPC.

References

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