A method for adaptive proton therapy for nasal cavity treatments

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Purpose.

The accuracy of proton dose distributions is strongly affected by range uncertainties, and the effect is even more important for Intensity Modulated Proton Therapy (IMPT) plans as compared to conventional radiotherapy.

Many factors contribute to such uncertainties and, among these, inter fractional changes play an important role; they are mainly due to patient positioning errors and anatomical changes. Daily image guidance can reduce the effect of positioning errors, and it could also be used for minimizing the effect of anatomical changes.

In this study we present a method to deal with anatomical changes that occur during treatment without re-planning. This problem is significant for patients treated in the nasal cavity area, where filling of the sinuses can be subject to change. For such patients, at PSI, the cavity filling is monitored regularly during the treatment by acquiring follow up CTs once per week (repeated CTs) and recalculating the nominal dose distribution on this CT data. The differences between nominal and recalculated dose distributions are computed to estimate if a new plan, optimized on the newly acquired CT, is necessary.

The goal of the method presented here is to avoid this re-planning process, by generating an atlas of CT data sets with artificially filled cavities. On these different CT sets, IMPT plans with field geometries identical to the nominal plan would be optimized and prepared for delivery such that, during the treatment course, such pre-calculated 'adapted' plans could be used as soon as anatomical changes are detected.

Method.

We considered two patients treated at PSI: the first presented with a adenocarcinoma of the nasal cavity, and the second with an undifferentiated epidermoid carcinoma in the left nasal cavity. Significant changes in cavity filling were detected for both patients during the treatment course and both were treated with a standard four field IMPT approach. For this study however, we have also analysed the effects on an alternative, three field IMPT plan (not applied clinically), which we assume is less robust to anatomical changes.

The foundation of this work is the generation of a 'database' of plans, based on different assumed fillings of the nasal cavities. To generate these, on the nominal planning CT, the paranasal sinuses were delineated and filled using different algorithms. The simplest option investigated was filling the whole sinus with different Hounsfield Units values ranging from -1000 HU to 230 HU, in seven steps (with 205 HU difference). Depending on the field direction each of the HU filling correspond to a different Water Equivalent Range (WER), corresponding to different levels of filling.

The other models were more representative of the clinical situations where the filling occurs on a layer-by-layer basis.

As the sinuses were delineated as three different cavities, and each of these could be filled in a different way, the atlas of CT data sets was composed of at least 27 CTs. For each of the repeat CT data sets (acquired for the patients during the treatment course), the best matching CT set out of this atlas was determined, based on similarity of sinus filling.The difference between the nominal and the artificially filled CT sets was evaluated after converting the CT data into WER data, for each of the fields of the IMPT plan. The atlas-CT with the lowest difference was considered to be the best matching planning CT, and was then used to optimize an IMPT plan,

the so-called plan of the day. For this plan, the optimization was performed in order to get similar dose sparing to the Organs At Risk (OARs) as for the nominal plan.
The differences between the nominal, the plan of the day and the plan recalculated on the repeat CT have been estimated. They were evaluated based on different dose parameters such as minimum, maximum, D2%, V98% in the target volume, dose difference histograms and the 3D gamma index.

Results.
Comparing between the models for cavity filling, the layered approach showed the best results as compared to the HU model. The differences between the dose distributions of the plan of the day recalculated on the repeated CT and the nominal plans were generally below 5% for the target dose parameters, with the exception of the maximum dose (differences up to 10%).
For the first patient, doses computed on the atlas-CT were similar or better than the recalculated nominal plans. As expected, the more robust four field IMPT plan resulted in lower differences in comparison to the nominal plan than the three field plan. Similar results were also found for the second patient.

Conclusions.
On line adaptation is a powerful tool to correct for proton range variations due to anatomical changes in the patient. The method presented here demonstrated that, for two patients, changes in the nasal cavity fillings could be modeled and used to generate a CT data sets atlas and consequently an atlas of IMPT-plans to compensate these changes. These initial results are promising, even though the filling algorithm could be improved. However, a Quality Assurance (QA) process for atlas based IMPT plans would be defined in order to be able to clinically adopt such a technique.