Modelling the effect of time varying organ deformations in head and neck cancer using a PCA model

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Introduction

Throughout the radiotherapy treatment process, geometrical changes in the patient often occur, e.g. organs differing in shape from that of the planning CT scan (pCT). This organ deformation leads to uncertainties in the dose distribution throughout the treatment course. We present a method to statistically model the time dependent effect of organ deformation on organ at risk (OAR) dose, with the aim of later incorporating it into advanced treatment planning methods i.e. probabilistic planning.

Materials & Methods

The planning CT scan (pCT) and 5 weekly cone-beam CT scans (CBCTs) were used from 10 head and neck cancer patients. Of these, 6 patients were treated to a prescription dose of 60 Gy, three patients (5-7) to 66 Gy and one patient (8) to 55 Gy. Figure 1 shows a flowchart of the steps involved for this method of simulating organ deformation. First, image registration was performed on each CBCT to produce a deformation vector field (DVF) mapping it to the patient's individual pCT. An average pCT of all the patients was next produced using a group-wise image registration, and deformation data from the population of patients was propagated to that scan. As a result, each voxel in the average pCT had 10 deformation vectors (one for each patient) for each week of treatment. Then, a principal component analysis (PCA) [1] was performed on the 10 DVFs for each week. This produced deformation eigenvectors of the 9 most dominant modes of deformation for each week with their respective variances. We created 5 models, each corresponding to a single treatment week to account for long-term trends in organ deformation throughout the treatment course.
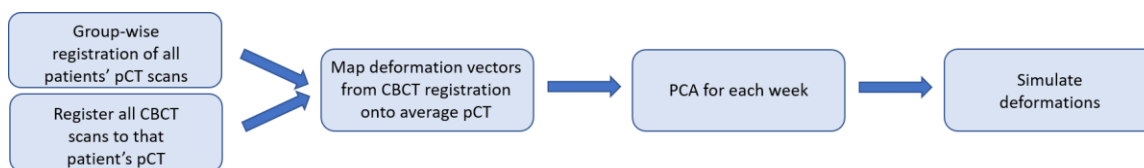

Figure 1: *Flowchart of the method used to simulate organ deformations.*

To simulate a potential deformation for a given week, random numbers were drawn from a Gaussian distribution with the variance of the corresponding mode and used to scale the contribution of that mode. The contributions of each mode were summed to create a total potential deformation for the given week.

100 different treatment courses were simulated for each patient, assuming 30 fractions each with a different time dependent deformation (6 deformations sampled from each of the 5 weekly models). The dose distribution for each patient was slightly extended outside the skin to account for potential motion of the

OAR outside the patient body, and then warped according to the potential deformation for each fraction. The warped fraction dose distributions were summed to get the cumulative dose distribution for each simulated treatment. Finally, the maximum dose to the brainstem and the mean dose to both parotids were calculated for each simulated treatment.

Results

The difference in the mean dose delivered to the parotids in each simulated treatment compared to the planned dose ranges from 5.7 to -4.7 Gy for the left and 6.0 to -4.0 Gy for the right. 5 patients showed a mean increase in dose to the left parotid across all treatments and 3 for the right. Averaged across all patients, a mean increase 0.1 Gy was found for the left parotid and a mean decrease of 0.3 Gy for the right. The difference in the maximum brainstem dose has a range from 7.0 to -6.5 Gy, with an average decrease of 1.0 Gy. Figure 2 shows boxplots of the dose difference for the brainstem and parotids of all 100 treatments for each patient. A small time-trend can also be observed, e.g. due to weight loss.
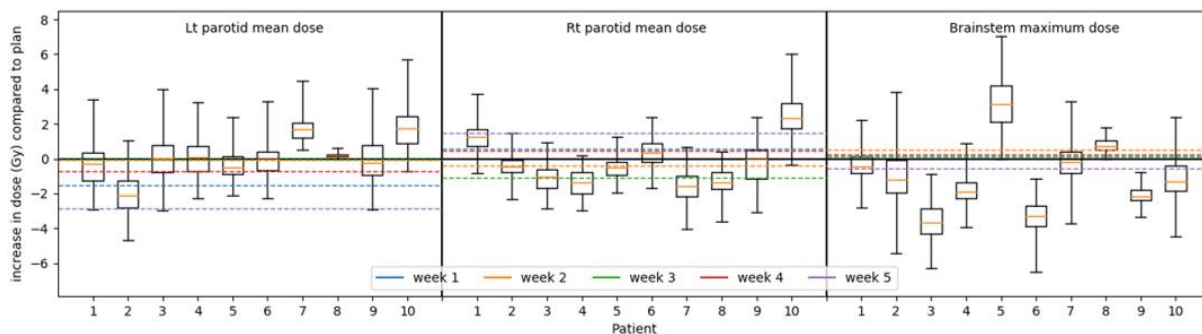

Figure 2: *Box-plots of deviations between planned and simulated mean dose in: (a) the mean dose of the left parotid (b), the mean dose of the right parotid (c) the maximum dose to the brainstem. The whiskers on each box-plot represent the range. 100 treatments were simulated per patient. The dotted lines represent the dose change from the pCT to the weekly CBCTs averaged over all patients.*

Discussion & Conclusions

We have implemented a methodology that allows us to simulate weekly organ deformations for individual head and neck cancer patients. This method will be used in probabilistic planning to optimize treatment plans directly accounting for organ deformation. For the patients analysed, the results show that large changes in the dose delivered to OARs result from organ deformations. There was a small shift in the overall mean difference between the planning and simulated doses delivered to the brainstem and parotids, but 'random' deformations often result in a larger change in dose.

References

[1] M. Söhn, et al., *Modelling individual geometric variation based on dominant eigenmodes of organ deformation: Implementation and evaluation.*, *Phys. Med. Biol.*, 50(24): 5893–5908, 2005.

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