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Dosimetric Results of Image Guided Tilt Corrections of Setup Errors for Nasopharyngeal Cancer Patients in Radiation Oncology

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1. Introduction

In the last decade the precise and stable positioning of the patient on the treatment table of the linear accelerator became one of the most important issues in radiation oncology. Nowadays, several image guidance methods, including gantry mounted x-ray facilities, like kilovolt (kV) and cone beam computed tomography (CBCT) or others, as well as surface sensors and online observation approaches, allow the localisation of the tumour or its surrogates in a six dimensional (3 orthogonal translations and rotations) space and in time. The observation undergoes a quantitative comparison with the tumour geometry in the CT based treatment plan resulting in a position correction information or a motion model.

Conventional treatment tables of linear accelerators allow manipulations of the patient in four degrees of freedom. The rotation degrees, tilt and roll are normally not addressed. However it was shown in literature that patients have a variation in pitch and roll of up to 4° during the course of their treatment (1, 2). In the meantime several robotic add on systems for corrections in six degrees of freedom (6DOF) are available to compensate for this deficit.

What is the benefit for the patient of those 6DOF table tops? The present study aims to quantify the potential of a 6DOF system for the clinical workflow and the consequences of a tilt correction capability on the dose distribution of VMAT or IMRT plans applied to patients with nasopharyngeal carcinoma (NPC). NPC is one of the most challenging tumours with respect to radiation treatment planning and delivery (figure 1), due to its location close to several sensitive organs (brainstem, brain, eyes, chiasm, optic nerves). Therefore, image guided tilt correction was thought to potentially translate into most benefit in NPC patients treated with a high radiation dose.

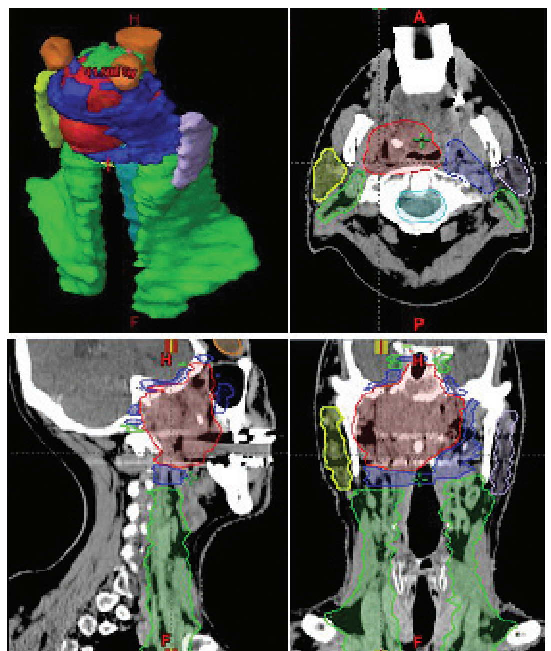

Figure 1: Representative nasopharyngeal cancer patient: Arrangement of four planning target volumes (PTV) receiving 54 – 70 Gy and organs at risk (OAR); 3D surface display and three orthogonal reconstructions (axial, sagittal, coronal).

2. Material and Methods

2.1 Patient treatments

As treatment device a Trilogy® linear accelerator with an orthogonal kV-imager (Varian Medical Systems) was utilized. In early 2011, the treatment table was equipped with a Protura™ 6 DOF table top (CIVCO Medical Solutions), which is based on hexapod robotics and replaced the carbon fibre table top. Due to this hexapod design Protura allows rotations around the isocenter.

All seven retrospectively analysed NPC patients were fixated with a five point thermoplastic mask and roughly pre-positioned. To adjust the exact position of the patient in each treatment session an orthogonal kV image pair was acquired and quantitatively compared with digitally reconstructed radiographs (DRR) using the six dimensional OBI® (Varian Medical Systems) matching software. As a result a set of five coordinates was obtained. Only the roll degree can not be derived from orthogonal x-ray images. Corrections in this degree of freedom make cone beam CTs (CBCT) necessary. To avoid the higher CBCT imaging dose to the patient it was decided to limit the current trial to the five degrees of freedom. Due to the fact that the lateral dimension of the PTV region is much smaller than the longitudinal dimension, the estimated benefit for a roll correction in this patient group is rather low.

The correction coordinates were transferred to the Protura controller and executed with three translations and with two orthogonal rotations around the isocenter.

2.2 Dosimetric evaluation of the pitch correction

All seven patients were treated using 5-7 field IMRT plans, designed to deliver 70 Gy to the planning target volume (PTV) 1 in 35 fractions; PTV2 received 66 Gy, PTV3 60 Gy and PTV 4 54 Gy. Treatment planning was performed in Eclipse® treatment planning system (Varian, Paolo Alto).

Patient pitch was simulated by tilting the planning CT in cranial – caudal direction by +/- 3° and +/-1.5°, which results in four different orientations. For that a copy of the original CT dataset was made, identifying DICOM tags were deleted, PTV structures and structures of organs at risk (OAR) were copied on the dataset and the dataset was tilted. A verification plan was calculated on the four tilted datasets. PTV coverage (volume receiving 95 % of the dose [V95%]) for PTV1 - PTV4 and mean and maximum dose to OARs were compared to the original plan. Box-Whisker-Plots showing the changes were created and differences were tested on significance using a paired Wilcoxon signed-rank test. A two-sided p value < 0.05 was considered statistically significant.

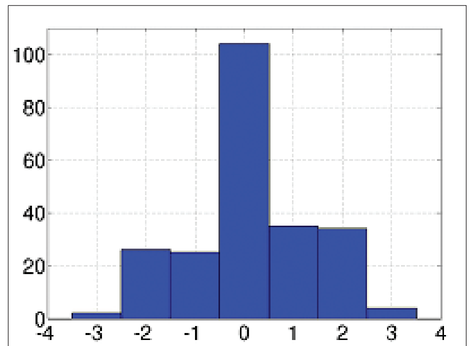

Figure 2: Distribution of pitch corrections for the first seven patients treated on the 6DOF table top.

3. Results

3.1 Pitch corrections

Figure 2 shows the distribution of pitch corrections for the first 7 patients treated on the 6DOF table top. A pitch of 0 means that no correction was applied, which is the case for pitches below 1° or when the table was not working due to technical problems.

3.2 PTV coverage

For a tilt of 3° the mean PTV coverage significantly was reduced by 2.7 % (1SD=2.2 %), for PTV 1, by 1.4 % (1SD=1.2 %), for PTV2 by 3.8 % (1SD=2.4 %), for PTV3 and by 4.3 % (1SD=4.2 %) for PTV 4 ($p<0.01$). There were no significant differences between a pitch in dorsal or in ventral direction. Maximum change in V95% for PTV1 was -7% and 9% for PTV4. Figure 3 shows an example of dose volume histograms for the original plan two three degree tilted plans. A tilt of 1.5° reduced coverage of PTV 1 by 1.4 % (1SD=1.5 %) and by 1.8 % (1SD=1.9 %) ($p< 0.01$) of PTV 4. Changes for PTV 2 and PTV3 were not significant.

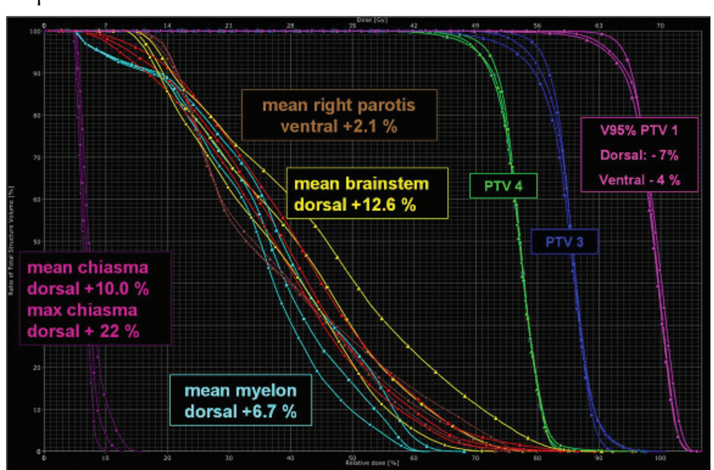

Figure 3: Dose volume histogram showing changes in PTV coverage and dose changes for selected OAR for one patient. ■ original plan, ▲ dorsal 3°● ventral 3°.

3.3 Dose to OAR

A dorsal pitch of 3° leads to sparing of the eyes ($p<0.01$) and an overdose to the spine, brainstem ($p<0.01$), brain and chiasm ($p<0.05$). A ventral pitch leads to sparing of the brainstem ($p<0.01$) and the brain ($p<0.05$) and the left eye became overdosed ($p<0.05$) (Figure 4). Changes in dose to the optic nerves and the parotic glands were large but not systematic. A dorsal pitch of 1.5° increased the maximum dose to the chiasm by 6.7 % (1SD=4.3 %, $p<0.05$), the mean dose to the brainstem by 2.9 % (1SD=1.5 %, $p<0.01$) and the mean dose to the brain by 1.9 % (1SD=1.6 %, $p<0.05$); the dose to the eyes was reduced by 2.8 % (1SD=2.7 %, $p<0.05$). A ventral pitch by 1.5 ° leads to a decrease in the mean dose to the brainstem by 4.9 % (1SD=3.9 %, $p<0.01$) and in the mean dose to the brain by 1.1 % (1SD=2.3 %, $p<0.05$). Maximum dose to the chiasm was reduced by 4.7 % (1SD=4.7 %, $p<0.05$).

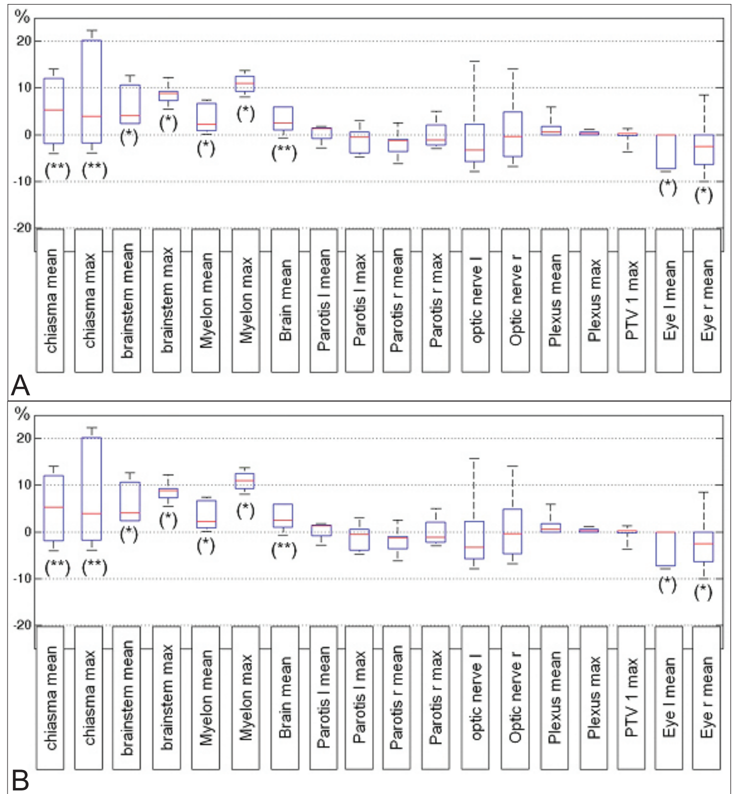

Figure 4: Boxplots showing the changes in dose if the patient is tilted A) dorsal and B) ventral by 3°.

4. Discussion and Conclusions

For nasopharyngeal cancer treatments, in more than 50% of the treatment sessions a tilt of 1° up to 3° in the patient setup has been detected in the lateral kV images. The Protura table was used to correct for these misalignments. If the patient is not corrected in this degree of freedom a tilt of 3° shows a significant effect on the coverage of the different integrated PTVs with prescribed doses ranging from 54 Gy to 70 Gy. The differences found for the volume receiving 95% of the dose (V95%) ranged up to 9% in the 70 Gy PTV with an average of 4.3 %. As expected, an uncorrected tilt of only 1.5° shows a smaller effect on the PTV coverage, which only was partly significant.

According to these effects on the tumour coverage there was an influence on the OAR sparing as well; with one difference: if the patient is tilted in a way that the head is lifted and the chest lowered (“dorsal pitch”), the doses to the brain and brainstem are increased and the sparing of parotids, optic nerves and eyes is improved. For the opposite rotation direction (“ventral pitch”) this behaviour becomes inverted. The reason for this fact is that for the ventral pitch direction (figure 5) the cranio-ventral and caudo-dorsal OARs are moving closer to the treatment region whereas the cranio-dorsal and the caudo-ventral OARs are moving away from the high dose volumes. For the PTVs an almost equal degradation of the dose coverage was found for both rotation directions, hence the PTV is leaving the high dose region for both directions.

The absolute volume of the single PTV, the dimensions in anterior posterior direction and the localisation along the longitudinal axis determine how sensitive the V95 reacts on a rotation in tilt. The treatment region for this tumour entity has a longitudinal dimension of 20 to 25 cm (figure 1). If the isocenter is placed in the longitudinal centre, a rotation by 1.5° effects in a displacement of 3 - 4 mm at the cranial or caudal end, a rotation by 3° translates in a displacement of 6 – 7 mm (Figure 5), which should be corrected, as the current study clearly shows.

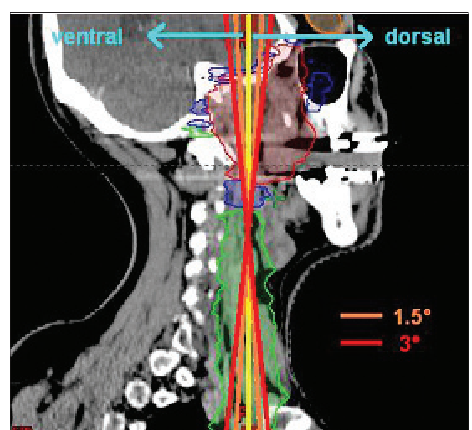

Figure 5: Scheme of the isocentrical tilt effect (1.5° and 3°) in a sagittal view.

Therefore a correction of the setup in the tilt degree could – depending on the case – be clinically relevant and should be performed in any nasopharyngeal cancer patient treatment. In certain critical cases, which are defined on an individual basis, even tilt misalignments of 1° should be adjusted.

References

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