Retrospective analysis of treatment plans robustness in image-guided carbon ion treatment of skull-base tumours.

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Clinical procedures for patient positioning are designed to minimize systematic errors in the treatment geometry. However, despite the use of advanced technologies, anatomical variations and practical issues limit the accuracy of daily setup. In addition, the estimation of stopping power for different tissues from CT data has intrinsic uncertainties.

In order to quantify the degradation of dose distribution due to such residual uncertainties, we have retrospectively tested the robustness of intensity modulated carbon ion plans for the treatment of clivus chordoma.

Materials and Methods

Ten patients treated at the Centro Nazionale di Adroterapia Oncologica (IT) were selected for this study. The treatment consisted of 16 fractions, 4.4 Gy (RBE) each. In our study we considered the enlarged PTV applied in the first 10 fractions before boosting the treatment to a smaller volume. The PTV was obtained by applying 2 mm expansion from the CTV. The brainstem was included as organ at risk, with a maximum 30% of the fraction dose.

We derived the setup errors from the clinical practice at the institution [1] featuring six degrees of freedom couch and 2D-3D image registration software. We have identified the ± 1.0 mm and $\pm 1.0°$ ranges to cover the 95% of observed residual setup errors. Orthogonal sampling was applied on the error space, thus defining 64 trials to explore the effects of setup errors in a statistically equivalent dataset. Accordingly, the patients' planning CTs were rigidly transformed and considered for dose recalculation.

Treatment planning was based on TRiP98 and LEM-I ($\alpha/\beta = 2$) using 6 mm beam FWHM with 2 mm by 3 mm raster grid in lateral and depth dimensions.

We have evaluated DVH bands at 95% ($D95_{CTV}$) and 105% ($D105_{CTV}$) dose for CTV and 5% ($D05_{OAR}$) for the brainstem. In addition, inhomogeneity (IC) and conformity (CI) indexes were calculated for the CTV.

Setup error cases resulting in larger variation on the target DVH were considered for the analysis of stopping power uncertainties. Only the worst-case scenario reported by Rietzel et al. [2] for head&neck tissues was considered, thus applying $\pm 2.6\%$ deviations from nominal values.

Results

On 7 patients out of 10, the $D95_{CTV}$ error was always below 10% in presence of setup errors. Instead, larger discrepancies were observed in combination with range uncertainties, whereas their effect on the organ at risk is related to the specific patient anatomy (Figure 1).

The CI_{CTV} exhibited reduced sensitivity to setup errors with respect to the IC_{CTV}. Conversely, range uncertainties affected significantly the CI_{CTV}, but minor variations were reported for IC_{CTV}. Higher values for IC_{CTV} in nominal conditions were reported to be prone to large deviation when uncertainties occur. Finally, a strong correlation ($\rho = 0.91$) was found between the nominal treatment plan IC_{CTV} and its score in presence of setup errors.
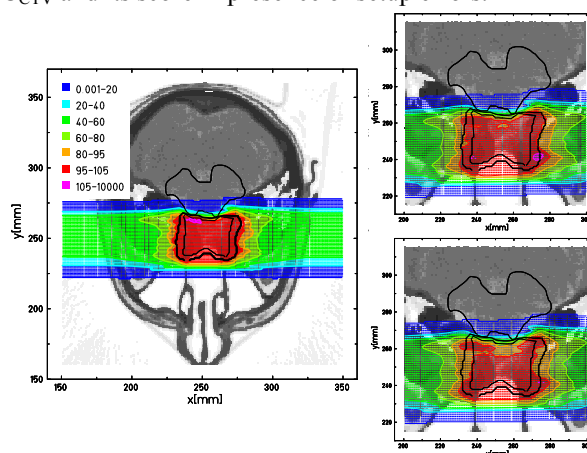

Figure 1: axial dose cut in nominal geometry (left panel), in presence of setup errors (top-right panel) and combination of setup and HU-WE uncertainties (bottom-right panel).

Conclusions and outlook

We have recalculated the patient dose in presence of setup and range errors to test the treatment plan robustness. Even though conformity is generally preserved, the combination of setup and range errors has an impact on the treatment quality. On this basis, we have further investigated the role of fractionation to mitigate the patient dose degradation [3].

References

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