Spinal cord tolerance

Regional cumulative maximum dose to the spinal cord in head-and-neck cancer: Considerations for re-irradiation

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ABSTRACT

Purpose: To present a new method that assesses the delivered maximum dose of different spinal cord sections in head-and-neck cancer treated with intensity-modulated radiation therapy (IMRT). This allows a more accurate estimation of the remaining cord dose tolerance in case of a later re-irradiation treatment planning.
Materials and methods: The suggested workflow is demonstrated using daily acquired kilo-voltage control-CTs of four head-and-neck cancer patients (118 control-CTs). The local maximum dose inside different cord levels is determined and accumulated for the planning situation and over the treatment course for an IGRT and a non-IGRT approach.
Results: The approach is suitable to accurately detect and document the delivered maximum dose dependent on the cord levels. The delivered maximum dose differed up to 13% from the planned one in all sections due to setup uncertainties and the applied correction strategy.
Conclusion: The presented approach facilitates later re-irradiation treatment planning due to detailed documentation of the delivered maximum dose to the spinal cord levels in the primary IMRT. The method also facilitates the interpretation of complex 3D dose information by reducing it to its essentials. This 2D illustration is an aid to orientation for the physician in the re-irradiation planning process.

Locoregional tumour recurrence after an initial full course of radiation therapy remains the predominant pattern of failure in head-and-neck cancer (HNC) patients [1,2]. In these patients, high-dose re-irradiation provides a possible treatment option with encouraging survival outcomes [3,4]. However, the risk of injury of critical structures like the spinal cord limits the maximum dose which can safely be delivered in the second irradiation course.

In a conventional non-IMRT treatment plan the entire cervical spinal cord receives a rather uniform dose. In contrast, the dose distribution along the levels of the spinal cord in IMRT plans is fairly irregular, with some areas of the cord receiving lesser or higher dose than others. Yet, an increasing number of patients receive IMRT as initial therapy due to improved quality of life after the radiation treatment [5,6].

In case of a re-irradiation, it is important to know the maximum dose values, the cord close to the region of tumour recurrence already received in the first IMRT treatment course. This information improves assessing the remaining spinal cord dose tolerance for the second irradiation course in this region. However, currently, the spinal cord dose tolerance to re-irradiation is subject to ongoing investigations. To determine this tolerance it is necessary to correlate the location of a radiation myelopathy with the delivered dose at the same location. Therefore, an accurate assessment and documentation of the delivered dose, instead of the planned dose, is requested.

If detailed information about the distribution of the planned local maximum dose values is requested, the cervical spinal cord needs to be sub-divided into sections in the IMRT treatment plan. This can be done, e.g. by contouring cervical cord sections, which are defined by the size of single cervical vertebrae as suggested by Parashar et al. [7].

However, the question arises whether during the first IMRT treatment course the actually delivered maximum dose values of these spinal cord sections exceed the planned ones. The occurrence of interfractional patient setup errors or changes in the anatomy can lead to discrepancies between the delivered and the originally planned dose values. In case of large dose deviations, this could have an impact on the remaining dose tolerance of the spinal cord in case of re-irradiation. Another aspect that might influence the delivered maximum dose is the treatment strategy which has been used in the first treatment course. Possible alternative strategies here can be an IGRT or a non-IGRT margin approach.

In this study we adopt and extend the concept of detailed regional dose analysis suggested by Parashar et al. [7], to present a

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method which allows for quantification of the actually delivered dose to the spinal cord. We refine the concept of Parashar by considering the maximum dose values of small spinal cord volume elements with the thickness of a single CT-slice. The approach allows assessing the impact of daily positioning variations of the spinal cord on the actually delivered maximum dose values along the body-axis. The gained information helps estimating the remaining cord dose tolerance of different cord sections. To demonstrate the procedure, we perform a dose analysis for two widely used treatment approaches, an IGRT and a non-IGRT approach.

Methods and materials

Patients

Four HNC patients with daily kilo-voltage control-CT scans were analysed retrospectively. All patients were treated postoperatively. Three patients were treated for oropharyngeal (patients 1–3) and one for hypopharyngeal cancer (patient 4). IMRT was performed using a 6 MV linear accelerator (Siemens Artiste) combined with an in-room, on-rail spiral CT-scanner. 28–32 control-CT scans per patient (total 118 CT-scans) with a resolution of $0.98 \times 0.98 \times 2.0 \text{ mm}^3$ and $0.98 \times 0.98 \times 3.0 \text{ mm}^3$, respectively were evaluated.

IMRT plans, margins, target point correction for IGRT

An integrated boost technique was used and 2 CTVs were delineated: The therapeutic CTV (CTV) encompassed the pre-surgical gross tumour volume, whereas the prophylactic CTV (pCTV) enclosed the supraclavicular, the upper and the lower cervical lymph nodes. Both CTVs were extended by a CTV-to-PTV margin of 3 mm to define the respective PTV and pPTV.

An IGRT plan and a non-IGRT plan with an additional safety margin were created to compare the two strategies. The additional safety margin was deduced in accordance to the van-Herk recipe [8], based on positioning variations of a cohort of 45 head-and-neck cancer patients. This additional margin accounted for 4 mm in patients 1–3 and 7 mm in patient 4. Dose prescriptions were 70.4 Gy to the PTV (single dose 2.2 Gy) and 57.6 Gy to the pPTV.

For the IGRT scenario a target point correction was performed. Therefore the initial IGRT plan was copied; the target point was modified according to the correction vector and a re-calculation of the dose distribution using the control-CT was performed. The required correction vector was determined using a rigid registration method based on mutual information. The registration accuracy in the presence of high contrasted structures was assessed to be better than the voxel size of the CT scans [9]. For this registration a registration box was used which encapsulated the PTV where the gross tumour was previously located. In contrast, in the non-IGRT setting, the treatment plan including the additional safety margin was applied on all control-CTs without a target point correction.

Spinal cord re-contouring and volume tracking

To assess the applied dose distribution of the spinal cord over the treatment course, re-contouring of this organ on each control-CT scan is necessary. Therefore, a deformable image registration approach can be used that automatically re-segments the cord. However, up to date, validation of deformable image registration is not straightforward and different registration algorithms result in diverging vector fields for the same data [10]. Additionally the interpretation of warped dose distributions under volume changes is currently subject of ongoing investigations [11,12].

To avoid these issues we adopted the following automated approach: A slice-wise 2-dimensional rigid registration of the region including the spinal vertebrae was performed on each control-CT scan in regard to the planning-CT scan. The resulting translations were applied to all slices of the spinal cord contour. These spinal cord contour slices represent single spinal cord volume elements. The translated volume elements now describe the changed bending of the spinal cord on the current control-CT. This approach ensures that the delineated volume of the cord is conserved during the treatment course, which in turn allows a plausible accumulation of the dose of these volume elements. Prior to the 2D contour adaptation a possible cranio-caudal (cc) shift is corrected using another registration process. It is performed to extract a possible (cc) shift of the whole spinal cord structure. For this purpose, a large registration box which includes the pPTV, is used to assess the cc-shift of the vertebrae. The resulting (cc)-translation is then applied in the respective fraction prior to the transversal adaptation. Finally, all adapted contours were checked by a radiation oncologist.

The described approach is already implemented in our treatment planning system and does not require any user interaction. After the spinal cord volume tracking, it is possible to calculate the maximum dose values of the actual dose distribution per slice, fraction and strategy. The approach allows performing a proper summation of the maximum dose values along the cc-axis.

In the following, for better differentiation of the maximum dose values, the single maximum dose value of the whole spinal cord volume is denoted *global maximum*. The maximum dose value/s of the single spinal cord volume elements are named *local maximum/-a*.

It also needs to be kept in mind that besides the patient setup, addressed in this simulation study, additional sources of uncertainties in the dose delivery to the patient exist, e.g. uncertainties related to linac performance, planning system dose modelling, etc. In this study, the term "delivered dose" is used to describe the dose calculated on the control-CTs in contrast to the planned one and does not take into account other uncertainties than those related to the geometrical variations.

Results

The local maxima of the cord dependent on their cc-position are presented. In Fig. 1, the curves are plotted for all fractions for one patient (patient 4). The variance of the curves (indicated by arrows in Fig. 1) reflects the cc-shift of the whole cervical vertebral spine occurring in each fraction. Patient 4 showed the largest cc-shift of all patients, amounting for ±2 CT-slices of 3 mm thickness, which is not negligible in case of performing dose accumulation.

The approximation for the dose accumulation of the local maxima is illustrated in Fig. 2 for the same patient, to visualise their summation fraction by fraction. The diagrams in Fig. 3 show the values after tracking the volume elements and accumulating their dose for both treatment strategies. For comparison, additionally plotted is the respective curve progression of the local maxima of the cord in the treatment plan (black line). The black and red arrows indicate the planned and the cumulative global maximum.

In patient 1, using IGRT the curves of the planned vs. actually delivered local maxima along the cc-axis are in very good agreement, the global maxima are located in the same CT slice. Without IGRT, the global maxima are positioned in two different CT-slices with a distance of about 10 cm in between. The cumulative global maximum is now located in the lower neck. The maximum dose value is 13% higher compared to the planned dose in this CT-slice.

In general, in patient 2, the planned and accumulated curves of the local maxima show a bigger discrepancy for both strategies compared to patient 1. There is only a small distance in between the location of the planned global and the two cumulative global