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Original Article

Evaluating the Need for Daily Image Guidance in Head and Neck Cancers Treated with Helical Tomotherapy: A Retrospective Analysis of a Large Number of Daily Imaging-based Corrections

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Abstract

Aims: Clinical implementation of image-guided intensity-modulated radiotherapy is rapidly evolving. Helical tomotherapy treatment delivery involves daily imaging before intensity-modulated radiotherapy delivery. This can be a time consuming resource-intensive process, which may not be essential in head and neck radiotherapy, where effective immobilisation is possible. This study aimed to evaluate whether an offline protocol implementing the shifts derived from the first few fractions can be an acceptable alternative to daily imaging for helical tomotherapy.
Materials and methods: We retrospectively analysed the set-up data of 2858 fractions of 100 head and neck cancer patients who were treated with daily online image guidance. Using summary data from all treatment fractions, we calculated the systematic error ($\sum$) and random error (σ) in each of the three axes, i.e. mediolateral (x), craniocaudal (y), anteroposterior (z). We also calculated the translational vector of each fraction of individual patients. We then simulated two no-action-level offline protocols where set-up errors of the first three (protocol F3) or five fractions (protocol F5) were averaged and implemented for the remaining fractions. The residual errors in each axis for these fractions were determined together with the residual $\sum$ and σ. Planning target volume (PTV) margins using the van Herk formula were generated based on the uncorrected errors as well as for the F3 and F5 protocols. For each scenario, we tabulated the number of fractions where the residual errors were more than 5 mm (our default PTV margin). We also tried to evaluate whether errors tended to differ based on intent (radical or adjuvant), anatomical subsite or weight loss during treatment.
Results: Analysis from this large dataset revealed that in the tomotherapy platform, the highest set-up errors were in the anteroposterior (z) axis. The global mean was 5.4 mm posterior shift, which can be partly attributed to couch sag on this system. Uncorrected set-up errors resulted in systematic and random errors of $\sum_{x,y,z}$ of 1.8, 1.7 and 2 mm and $\sigma_{x,y,z}$ of 1.7, 1.5 and 1.9 mm, with a required PTV margin in x, y, z axes of 5.7, 5.3 and 6.2 mm. Implementing average shifts from the first three or five fractions resulted in a substantial reduction in the residual systematic errors, whereas random errors remained constant. The PTV margins required for the residual errors after three and five fraction corrections were 3.8, 3.4 and 5.1 mm for F3 and 3.3, 2.9, 4.8 mm for F5. The proportions of fractions where there was >5 mm residual error were 1.6%, 1.1%, 2.9% in x, y and z axes in the F3 protocol and 1.5%, 0.8% and 2.6% with the F5 protocol. Although there was no difference in residual shifts > 5 mm, there was a statistically higher chance of residual errors > 3 mm larynx/hypopharynx subsites versus other sites. In patients who had more than 5% weight loss, there was no significant increase in residual errors with the F5 protocol and the required PTV margin was within our default PTV margins expansion.
Conclusions: Correction of systematic errors by implementing average shifts from the first five fractions enables us to safely avoid daily imaging in this retrospective analysis. If this is validated in a prospective group it could lead to implementation of a resource sparing image-guided radiotherapy protocol both in terms of time and imaging dose. Patients with larynx/hypopharynx subsites may require more careful evaluation and daily online matching.

Key words: Helical tomotherapy; PTV margin; set-up errors

Introduction

Head and neck cancer radiotherapy has evolved with the advent of conformal radiotherapy techniques. Intensity-modulated radiotherapy (IMRT) is now commonly used for achieving adequate dose coverage while sparing critical structures in the complex head and neck anatomy. In addition, IMRT is able to reduce dose to the parotid glands, resulting in a clinically significant reduction of xerostomia [1]. Planning and delivery of highly conformal treatments

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like IMRT is challenging, as there is a risk of target miss due to daily positioning, set-up and anatomical uncertainties. Image-guided radiotherapy is now an integral part of IMRT delivery in most centres, with several in-room imaging options. Image-guidance protocols are linked to the selection of target volumes, immobilisation strategies and planning target volume (PTV) margins.

Helical tomotherapy is one of the established platforms that combine helical delivery of IMRT with image guidance using an in-room megavoltage computed tomography (MVCT) in head and neck cancer [2,3]. Daily online image guidance is the default practice on this platform [4]. This allows pre-treatment correction of both systematic and random interfraction set-up errors.

However, daily online image guidance is resource-intensive and time-consuming. A typical MVCT scan in the treatment position followed by online matching and couch adjustments takes 6–8 min for each fraction. Each MVCT image acquisition also delivers an imaging dose of 1–3 cGy to the patient depending on the mode used [4].

The benefit of daily online imaging would depend on the nature and magnitude of interfraction set-up uncertainties. In some anatomical sites like the prostate, there are large random errors, and online corrections are recommended [5]. In large dataset analyses of set-up errors from multiple anatomical sites based on volumetric imaging with MVCT on the tomotherapy platform, it has been noted that compared with pelvic and thoracic primaries, both the systematic and random uncertainties in head and neck cancer are considerably smaller [6,7]. This is probably due to effective immobilisation and reproducibility of set-up positioning.

In settings where set-up errors are small, the necessity of daily pre-treatment imaging warrants comparison with simpler offline protocols. Offline protocols can effectively reduce systematic errors. Several offline protocols have been well studied since the advent of two-dimensional in-room imaging. Of the available choices, the no-action-level (NAL) protocol has perhaps been the most extensively studied [8]. It is widely used and recommended as a standard model of offline correction [9].

If an offline imaging protocol can be safely implemented on the helical tomotherapy platform for head and neck cancer, it could be highly resource sparing, and additionally reduce radiation exposure from imaging for several patients.

The primary objective of this study was to determine the nature and magnitude of set-up errors for a large cohort of head and neck cancer patients treated on the helical tomotherapy system, and to determine if an offline image guidance protocol can be implemented without increasing our standard PTV margins of 5 mm. A secondary objective was to identify subgroups, based on parameters like anatomical site and weight loss, where daily uncertainties could be higher, and offline protocols potentially less safe with IMRT.

Materials and Methods

In this retrospective observational cohort study we analysed the set-up data of 2858 fractions of 100 head and neck cancer patients who were treated with daily online image guidance on helical tomotherapy. All patients were treated with five point immobilisation with thermoplastic sheets.

All patients were imaged daily before treatment delivery. In the scan settings, the length of the scan was set daily to cover the entire PTV length (as determined from the contours visible in this window). The scan was carried out using either the coarse (6 mm nominal slice thickness, 12 mm couch shift per rotation) or normal setting (4 mm nominal slice thickness, 8 mm couch shift per rotation), based on the location of the high dose region. The normal setting was more frequently used for patients with high dose regions close to the brainstem or optic structures. The scan length was initially automatically matched using the 'Bone + Soft-tissue' setting, with axes of matching set to 'Translations + Roll'. A roll value of >2 degrees required a repositioning. Each automatic match was reviewed manually, focussing on the area containing the gross tumour volume or high dose volumes, and adjustments made to the match.

Using summary data from pre-treatment MVCT before each of the treatment fractions, the shifts in the mediolateral (x), craniocaudal (y) and anteroposterior (z) translational axes were tabulated and the error vector also calculated $\sqrt{(x^2 + y^2 + z^2)}$. From this dataset, we calculated the systematic error ($\sum$) and random error (σ) separately for each of the three axis, as well as the error vector.

We then simulated two variations of the NAL offline correction protocol where set-up errors of the first three (protocol F3) or five fractions (protocol F5) were averaged and implemented for the remaining fractions, and the residual errors in each axis for these fractions were determined together with the residual $\sum$ and σ. PTV margins using the van Herk formula (PTV $= 2.5\ \Sigma + 0.7\ \sigma$) were generated based on the uncorrected errors as well as for the residual errors after NAL based F3 and F5 protocols [10].

For each scenario, we tabulated the number of fractions where the residual errors were more than 5 mm (our default PTV margin).

We also tried to evaluate whether errors tended to differ based on intent of treatment (radical or adjuvant) and anatomical subsite (lower neck primaries in the larynx/hypopharynx versus other sites). In a subset of 86 patients in whom pre- and post-treatment weights were clearly documented, we also analysed whether set-up accuracy differs in patient who had less than 5% weight loss compared with those who had 5% or more weight loss.

Set-up data were tabulated and analysed using a spreadsheet program (Microsoft Excel – Office 2010). The chi-squared test was used to compare the frequency of large residual errors between the groups. Statistical significance was assumed at $P < 0.05$, with all tests being two-tailed.

Results

The set-up data of 2858 fractions of 100 head and neck cancer patients who were treated with daily online image