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IGRT in head and neck cancer

Does IGRT ensure target dose coverage of head and neck IMRT patients?

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ABSTRACT

Purpose: To determine if image-guided radiotherapy (IGRT) ensures dose coverage to the target, and to assess the dosimetric impact of anatomic changes using megavoltage cone-beam CT (MVCBCT) for patient positioning during head and neck IMRT.

Methods and materials: Forty-eight MVCBCT from 10 head and neck IMRT/IGRT patients were analyzed off-line. Target volumes and organs at risk (OARs) contours delineated on CT were transferred and adjusted on MVCBCT images. Each MVCBCT was processed to allow dose recalculation, resulting in 469 dose–volume histograms (DVHs). The concept of dosimetric latitude was introduced to provide a clinical perspective.

Results: MVCBCT target DVHs showed a moderate level of difference in D95 (dose to ⩾95% of volume), generally less than a 5% difference from the planned dose. Delivered-dose increases to the spinal cord and brainstem showed no apparent time trend. The 4 mm margin around OARs was a useful precaution to prevent exceeding critical dose thresholds. The parotid glands showed progressive increases in mean dose related to shrinkage of the external contours.

Conclusion: IGRT repositioning ensured target volume coverage, but significant dose variations were observed for OARs. The dosimetric impact of anatomic changes during radiotherapy was of lesser importance than the effects of IGRT repositioning.

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Image-guided radiation therapy (IGRT) [1,2] has received a major boost over the last decade due in part to the development of on-board cone-beam CT (CBCT) capable of providing volumetric images of a patient in the treatment position, allowing for verification of setup and target localization in quasi-real time. As such, IGRT has become a valuable tool to ensure that the target is correctly located immediately before the dose is delivered. As a consequence, studies are being conducted to quantify the volumetric and positional changes of target and organs at risk [3]. An interesting by-product of IGRT is the availability of a 3D image representing the anatomy of the day in the treatment position, thereby opening up the possibility of assessing the actual delivered dose and evaluating the dosimetric impact of gradual anatomic changes and daily positioning variations.

The megavoltage (MV) cone-beam (CB) CT (MVCBCT) system is one of the IGRT devices currently available for clinical use. It utilizes the treatment beam of a conventional linear accelerator with an electronic portal imager [4,5].

It has been shown that MVCBCT images can be used to accurately evaluate the delivered dose by calculating the dose distribution on the MVCBCT (MVision MVCBCT system) [6,7]. This approach can be used to monitor the dosimetric effect of residual anatomic mismatches between the MVCBCT and the reference planning CT caused by the patient's plasticity, as well as substantive anatomic changes related to tumor shrinkage, radiation-induced edema, or weight loss [8–11]. Different groups have shown that MVCBCT-generated dose–volume histograms (DVHs) can be plotted, and differences between the planned and delivered dose distributions can be assessed through dose difference maps [12–17].

Complex and multifactorial dosimetric variations [9,10,12–18] occur during head and neck intensity-modulated radiation therapy (IMRT). One should therefore evaluate the impact of using IGRT for patient positioning on real-world dose delivery. The objective of this work was to determine if, by providing proper target alignment, IGRT ensured adequate dose coverage to the target. A second objective was to assess the dosimetric impact to organs at risk and the target of anatomic changes over the course of treatment. Dose–volume histograms (DVHs) were recalculated for volumes of interest delineated on MVCBCT images and these were compared with the expected planning DVHs. In order to provide an adequate clinical perspective, the concept of dosimetric latitude was introduced.

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Materials and methods

Original plans and determination of dosimetric latitude for volumes of interest

Initial IMRT planning was carried out on the Pinnacle[3] Radiation Therapy Planning System (Philips Medical). A simultaneous integrated boost technique was used, usually including two to three dose levels prescribed to different planning target volumes (PTVs) according to the expected risk of disease recurrence. The IMRT plans were optimized to achieve 95% coverage of the PTVs by the prescribed dose while respecting a standardized set of dose constraints to the delineated organs-at-risk (OARs). For the spinal cord and the brainstem, strict dosimetric limits were applied to the organ plus a margin, the totality of which constituted a planning organ at risk volume (PRV). For other OARs, no margin was applied and the dose limits were goals that could be exceeded if necessary to maximize the target coverage. Table 1 summarizes the OAR dose thresholds used to generate the IMRT plans.

For the purposes of this study, for each OAR, the DVH data extracted from the initial plan were compared with the corresponding dosimetric constraint. If the threshold had already been reached or exceeded, the OAR was considered to have no dosimetric latitude during the treatment course. If the threshold was not reached, the amount of dosimetric latitude was defined as the difference between the planned dose and the maximal threshold.

The degree of latitude in relation to the adequacy of target volume coverage was studied as well. For PTVs, the original planning goal, as defined by ⩾100% of the prescribed dose delivered to ⩾95% of the volume, was considered first. In fact, almost all of the patients barely reached this goal, leaving nearly no latitude for the great majority. Thus, a less stringent but tolerable goal was defined as a critical inferior threshold that should not be broken (⩾95% of the prescribed dose delivered to ⩾95% of PTV). For gross tumor volumes (GTVs), dosimetric constraints were kept at a more exigent level, with the goal maintained at ⩾100% of the prescribed dose delivered to ⩾95% of the volume.

IGRT process: MVCBCT to CT registration

Upon completion of the reconstruction image, the cone-beam image is automatically loaded in the Adaptive Targeting Software™, and the CB to CT image registration is performed automatically in few seconds using a mutual information algorithm. Using a large, open field for CBCT acquisition avoids the need for multiple gantry rotations and couch movements. In the current software version, rotations have been disabled from the registration. The system can display each CT with a different color scheme, and the transparency levels can be adjusted to visualize either CT or the MVCBCT image sets. The table shift correction is constantly updated as the user fine-tunes the registration. The MVCBCT and the reference planning CT are matched and resulting shifts are applied to the couch for correction of setup inadequacy before treatment. More details on the registration process and precision can be found at Refs. [3] and [4]. Because patients are not rigid [5,6], a completely exact match is rare. Clinically acceptable compromise is often required, with exact matching being limited to selected anatomic structures judged most critical by the treating physician. To ensure consistency, the therapists at the treatment unit are trained to systematically use the same structure to align a patient throughout the course of radiotherapy. The resulting CT–MVCBCT registration is stored with the images and use off-line for dose recalculation. This guaranties that the dose recalculation is performed on the MVCBCT image correctly positioned relative to the CT (see section on dose recalculation).

Table 1
Dose constraints used in the IMRT optimization process.

	Dose thresholds
Spinal cord^{+4mm}	$D_{1\%}$ < 45 Gy
BS^{+4mm}	$D_{1\%}$ < 55 Gy
Parotids	D_{mean} < 26 Gy
Cochlea	D_{mean} < 45 Gy
Mandible	$D_{1\%}$ < 75 Gy
Larynx	D_{mean} < 25 Gy

Abbreviations: BS = Brainstem, $D_{1\%}$ = Dose received by ⩾1% of the volume. D_{mean} = Mean dose received by the volume. +4 mm = 4 mm 3D automatic expansion.

Volume segmentation on MVCBCT images

All MVCBCT images were obtained with low-dose image acquisition protocols [4,5] with institutional review board approval.

In order to collect MVCBCT-generated dosimetric data for the relevant anatomic areas, specific regions of interest were defined on the MVCBCT images (Fig. 1). Because soft tissue contrast is not as good on MVCBCT as on a regular diagnostic CT, and to avoid potential variability in delineation carried out by different users, the initial volumes delineated on the planning CT by the treating physician were directly transposed from the CT to the registered MVCBCT images using the registration between the MVCBCT and the planning CT that had been used to position the patient on the day of treatment. MVCBCT images enabled accurate visual recognition of bony structures, air cavities, and interfaces between fat and main muscles of the neck. Using these anatomic landmarks, the adequacy of the transposition of the volumes of interest could be readily verified. Because of patient plasticity, residual mismatches were sometimes observed in the projection of volumes of interest from the planning CT. Thus, only if required, the volumes were minimally shifted to accurately align with clearly visible anatomic interfaces identified on the MVCBCT. The final segmentation of volume of interest on MVCBCT images was always validated by a head and neck radiation oncologist.

In addition, the patient's external contours were automatically generated on the MVCBCT images. For superficial volumes of interest, the automatic generation of the external contour was associated with an automatic exclusion of any part of the volumes ⩽3 mm under the skin. This approach is consistent with the technique used at our institution for planning or re-planning patients mid-course, in which the original volumes are maintained while removing any volumes that extend beyond the skin [19].

When present on the planning CT, gross tumor volume (GTV), planning target volume assigned to the highest dose (hPTV) and OARs including spinal cord, spinal cord plus a 4 mm expansion margin, brainstem, brainstem plus a 4 mm expansion margin, parotid glands, cochlea, mandible and larynx were transferred to the MVCBCT images. Volumes of interest for which the projection was outside the field of the MVCBCT were not considered.

Dose recalculation with MVCBCT images

In order to use the MVCBCT images for dose calculation, artefacts correction methods for the head and neck have been validated [5,15]. Because of missing data in the shoulder area due to the limited field of view of the MVCBCT system, each cone-beam image was completed using the planning kVCT image as a Ref. [16]. A complete description of the process of performing dose recalculation on MVCBCT images has been previously published [12].

Dose calculations performed on corrected MVCBCT images agree with calculations done on kVCT images to an accuracy of within 1% on phantoms and 3% using actual patient images. This

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