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PHYSICS CONTRIBUTION

RETROSPECTIVE IMRT DOSE RECONSTRUCTION BASED ON CONE-BEAM CT AND MLC LOG-FILE

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Purpose: Head-and-neck (HN) cone-beam computed tomography (CBCT) can be exploited to probe the IMRT dose delivered to a patient taking into account the interfraction anatomic variation and any potential inaccuracy in the IMRT delivery. The aim of this work is to reconstruct the intensity-modulated radiation therapy dose delivered to an HN patient using the CBCT and multileaf collimator (MLC) log-files.

Methods and Materials: A cylindrical CT phantom was used for calibrating the electron density and validating the procedures of the dose reconstruction. Five HN patients were chosen, and for each patient, CBCTs were performed on three separate fractions spaced every 2 weeks starting from the first fraction. The respective MLC log-files were retrieved and converted into fluence maps. The dose was then reconstructed on the corresponding CBCT with the regenerated fluence maps. The reconstructed dose distribution, dosimetric endpoints, and DVHs were compared with that of the treatment plan.

Results: Phantom study showed that HN CBCT can be directly used for dose reconstruction. For most treatment sessions, the CBCT-based dose reconstructions yielded DVHs of the targets close (within 3%) to that of the original treatment plans. However, dosimetric changes (within 10%) due to anatomic variations caused by setup inaccuracy, organ deformation, tumour shrinkage, or weight loss (or a combination of these) were observed for the critical organs.

Conclusions: The methodology we established affords an objective dosimetric basis for the clinical decision on whether a replanning is necessary during the course of treatment and provides a valuable platform for adaptive therapy in future. © 2008 Elsevier Inc.

Cone-beam CT, Head and neck IMRT, MLC log-file, Dose reconstruction, Adaptive radiation therapy.

INTRODUCTION

Two implicit assumptions are made in the current multileaf collimator (MLC)-based intensity modulated radiotherapy (IMRT) process. First, the geometric sizes, shapes, and locations of the targets and organs (internal anatomy) and the geometric topography of the patient are the same as at the time of computed tomography (CT) simulation throughout the treatment course. Second, the delivered fluence maps are the same as the planned ones and delivered by the MLC in an idealized manner. In reality, neither of these assumptions is guaranteed in clinical situations.

Many patients, especially those with head and neck (HN) cancers who undergo fractionated RT course, have marked geometric changes in their internal anatomy and topography during the treatment course, which are attributable to organ deformation, tumor shrinkage, weight loss or a combination of these (1, 2). These geometric changes might cause undesirable underdosage of the targets and potential overdosage of the critical organs in the vicinity of the targets and lead to a suboptimal treatment outcome. This issue poses a particular concern in HN IMRT cases because of the steep dose gradient that often exists between the boundary of the target and critical organs in an IMRT plan. The use of the three-dimensional (3D) patient model derived from a single planning CT (pCT) set to guide the fractionated RT course is a major hurdle to further advancing the radiation therapy (3). Recently, many in-room imaging modalities including CT-on-rail (4), kilovoltage-CBCT (5, 6), megavoltage cone-beam CT (7), and tomotherapy system (8) have been developed to monitor the geometric changes on a temporal basis. These new imaging modalities are primarily designed to verify and correct the patient's setup in a 3D space with respect to the pCT on the basis of bony landmarks, as well as soft tissue structures,

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before dose delivery. In principle, the CBCT can be further exploited to derive a 3D patient model for dose reconstruction to reflect the dosimetric impact resulting from the residual setup errors and geometric changes occurring over time.

Feasibility studies have been carried out by several research groups to reconstruct the IMRT dose distribution using CBCT and the planned fluence maps from the treatment planning system (TPS) (9–11). This maneuver is based on the second assumption mentioned earlier that the planned fluence maps can be faithfully realized by the delivery system (11). However, in a MLC-based IMRT using the step-and-shoot method, there may be errors associated with the control of leaf motion and fractional monitor unit (MU) delivery such as overshoot, undershoot segmental MU, dropped segments, and beam delivery during leaf motion (12–15). These factors might affect the dose delivery and result in a delivered fluence map different from the planned one. A more pragmatic approach in reconstructing the delivered dose is to use the fluence maps actually delivered for the treatment; therefore, we propose retrieving the MLC log-file that records the leaf position of each individual leaf and the fractional MU status during the delivery of IMRT from the MLC workstation and deriving the delivered fluence map from it.

The objective of this study is twofold: (*1*) to establish a methodology and procedures to reconstruct the dose delivered to a patient on a series of kV-CBCTs taken during a treatment course using the delivered fluence maps derived from the corresponding MLC log-files and (*2*) to study the potential dosimetric impact on the intended treatment plan taking into account the patient's geometric changes over time, residual setup errors, and the inherent delivery errors associated with the MLC. This work can serve as a platform for implementing a workflow in reconstructing the IMRT delivered dose and providing the necessary dosimetric information needed to modify the treatment plan, if indicated, on the basis of the accumulated dose given to the patient.

METHODS AND MATERIALS

CBCT image acquisition

The CBCT images in this study were acquired by the onboard imager (OBI) integrated in a Trilogy medical linear accelerator (Varian Medical Systems, Palo Alto, CA). The OBI system is mounted on the gantry of the linear accelerator perpendicular to the beam axis of the MV beam by robotic arms. The OBI system consists of a kV X-ray tube assembly at one end and an amorphous silicon flat-panel image receptor (39.7 cm × 29.8 cm) (Varian 4030CB flat panel) facing the X-ray tube at the other end in the full-extended configuration. The focus of the X-ray tube and the center of the image receptor are at 100 cm and 50 cm from the isocenter, respectively, resulting in a source-to-imager distance of 150 cm. The OBI isocenter coincides with the MV treatment isocenter within ± 1.5 mm and is routinely checked in the weekly quality assurance procedure (16). The CBCT can be acquired in two modes, the ''half-fan'' mode and ''full-fan'' mode. The half-fan mode is designed to increase the field-of-view (FOV) beyond 24 cm and was used exclusively in this study. In the half-fan mode, the image receptor is displaced laterally by 14.8 cm, and the blades of the X-ray tube are offset to cover the detector area. A half-bowtie filter is used in this mode. A half-fan projection image is acquired for each acquirement angle for the 364° gantry rotation in about 60 s, resulting in a total of 640–700 projections (16). Only part of the object is viewed in one half-fan projection; the other part of the object is viewed in the half-fan projection from the opposite position. The entire object is reconstructed by using the projections acquired 180° apart. The FOV and longitudinal coverage in this mode are 45 cm in diameter and 15 cm in length, respectively. A total of 640 projections are acquired and reconstructed into CBCT images of 512 × 512 matrix.

Electron density calibration

Electron density calibration was performed by scanning a phantom with inserts of known relative electron densities with respect to water (ρ_e^w) and calibrating the ρ_e^w against the Hounsfield units (HU) of the inserts. A 20-cm cylindrical CT phantom, Catphan-600 with CTP404 module (Phantom Laboratory, NY), was used for the electron density calibration for the pCT (GE Discovery-ST PET/CT scanner, Milwaukee, WI) and CBCT. This phantom was chosen because it has a size and shape comparable to a patient's HN region. Designated scanning parameters for HN patients were chosen for the pCT and similar scanning parameters were applied as far as possible for the CBCT; the slice thickness used was 2.5 mm. The half-fan CBCT mode (half-bowtie mounted) was used to give a FOV of 45 cm, comparable to that of 45–50 cm used in pCT to include the lower neck region. Both CT sets had a pixel size of about 1 mm in a 512 × 512 matrix image. The techniques for the CBCT used were 125 kVp, 80 mA, and 25-ms pulse, which are precalibrated for clinical use. The HUs of the inserts for both the pCT and CBCT were measured from the acquired images and plotted against the known ρ_e^w. The vertical and horizontal HU profiles of the same images were also plotted and compared. The temporal CBCT HU stability has been investigated by our group, and there is no significant fluctuation observed over a period of 8 weeks (10).

MLC log-file retrieval and processing

The Trilogy is equipped with the Millennium 120-leaf MLC (Varian Medical Systems) capable of IMRT delivery. During a step-and-shoot IMRT delivery, the MLC workstation logs the position of each individual leaf and the fractional MUs delivered every 50 ms; it also produces two separate log-files for each leaf bank (A and B sides). A split IMRT field results in four such MLC log-files. These automatically generated MLC log-files have been validated to represent accurately the actual IMRT delivery (17, 18). For this study, the MLC log-files were retrieved from the MLC workstation after the treatment session in which the CBCT was performed; the leaf positions and delivered fractional MUs were extracted and converted to leaf sequence files by software developed in-house, written in Visual Basic 6.0 code (Microsoft, Bellevue, WA). The leaf sequence files were then imported back into the TPS to regenerate the delivered fluence maps, which were used in the dose reconstruction on the CBCT-derived 3D patient model (Fig. 1). To access the practicability of the retrieval and conversion procedures, the MLC log-files of a HN IMRT patient were retrieved, and the subsequently regenerated fluence maps were attached to the original treatment fields in the IMRT plan. The dose was reconstructed using the original set of pCT; the resultant dose distribution and dose volume histograms (DVH) of the target and organs were then compared with those from the original plan to see the discrepancy due solely to the difference in the fluence maps used.

Phantom study

Planning CT and CBCT were acquired for the Catphan-600 phantom using the techniques previously described. Both sets of images