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Comparison of 3-dimensional dose reconstruction system between fluence-based system and dose measurement-guided system

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A B S T R A C T

COMPASS system (IBA Dosimetry, Schwarzenbruck, Germany) and ArcCHECK with 3DVH software (Sun Nuclear Corp., Melbourne, FL) are commercial quasi-3-dimensional (3D) dosimetry arrays. Cross-validation to compare them under the same conditions, such as a treatment plan, allows for clear evaluation of such measurement devices. In this study, we evaluated the accuracy of reconstructed dose distributions from the COMPASS system and ArcCHECK with 3DVH software using Monte Carlo simulation (MC) for multi-leaf collimator (MLC) test patterns and clinical VMAT plans. In a phantom study, ArcCHECK 3DVH showed clear differences from COMPASS, measurement and MC due to the detector resolution and the dose reconstruction method. Especially, ArcCHECK 3DVH showed 7% difference from MC for the heterogeneous phantom. ArcCHECK 3DVH only corrects the 3D dose distribution of treatment planning system (TPS) using ArcCHECK measurement, and therefore the accuracy of ArcCHECK 3DVH depends on TPS. In contrast, COMPASS showed good agreement with MC for all cases. However, the COMPASS system requires many complicated installation procedures such as beam modeling, and appropriate commissioning is needed. In terms of clinical cases, there were no large differences for each QA device. The accuracy of the compass and ArcCHECK 3DVH systems for phantoms and clinical cases was compared. Both systems have advantages and disadvantages for clinical use, and consideration of the operating environment is important. The QA system selection is depending on the purpose and workflow in each hospital.

Introduction

It is understood that the complex dose distributions produced by intensity-modulation radiation therapy (IMRT/VMAT) techniques require thorough and frequent verification.[1] The desire to streamline these measurements in clinical practice precipitated the development of electronic dosimetry arrays which provide essentially real-time measured dose readout and comparison to the planned dose distribution. Commercially available devices come in the form of planar[2] or, more recently, quasi-3-dimensional (3D) arrays.[3,4] These arrays provide not only 3D dose information on the phantom but also the 3D dose distributions in human anatomy.

However, it is impossible to measure the 3D dose distributions on patients directly. In this study, 2 quasi-3D dosimeters are compared. One is COMPASS (IBA Dosimetry, Schwarzenbruck, Germany) and the other is ArcCHECK with 3DVH software (Sun Nuclear Corp., Melbourne, FL). COMPASS uses Matrixx (IBA Dosimetry, Schwarzenbruck, Germany) planar diode arrays,[5] while ArcCHECK employs a helical diode pattern.[6] Both devices have the ability to reconstruct 3D VMAT dose distributions with high spatial resolution, equaling that of the treatment planning system (TPS) for any given plan. COMPASS reconstructs the volumetric dose distribution on the patient anatomy based on fluence measured with the MatriXX,[7] while 3DVH software uses the measurement-guided dose reconstruction and planned dose perturbation algorithms to reconstruct the dose on the arbitrary planning dataset.[3]

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Both the devices have undergone extensive independent validation,[8–10] but certain aspects of their performance have never been evaluated. Cross-validation to compare them under the same conditions such as a treatment plan will offer clear evaluation of these measurement devices. Meanwhile, a simulation such as Monte Carlo simulation (MC) is indispensable for dose evaluation in the human body.

The purpose of this study was to investigate the accuracy of reconstructed 3D dose distributions from the COMPASS system and ArcCHECK 3DVH using MC for multi-leaf collimator (MLC) test patterns and clinical VMAT plans.

Methods and Materials

The COMPASS system—Fluence-based system

The COMPASS system consists of a MatriXX 2D array based on a pixel ionization chamber, an integrated software solution comprising an algorithm which models the linear accelerator head and detector and an angle sensor. The detector assembly was mounted in a holder attached to the treatment head of a Varian Clinac iX (Varian Medical Systems, Palo Alto, CA) linear accelerator with a source-to-detector distance of 76.2 cm (Fig. 1). The MatriXX has 1020 ion chambers at intervals of 7.6 mm. On top of the detector, solid water slabs (RMI-457, GAMMEX, Schwarzenbruck, Germany) of 2 cm thickness were used for extra build-up and removal of electron contamination. The COMPASS system requires measured fluence (response) data with the MatriXX detector mounted on the linear accelerator head. 3D dose distributions in patient anatomy from the COMPASS system are then calculated with the collapsed-cone superposition algorithm based on the measured fluence and the patient computed tomography (CT) dataset from the TPS. We checked the beam modeling for the COMPASS system using open simple fields.

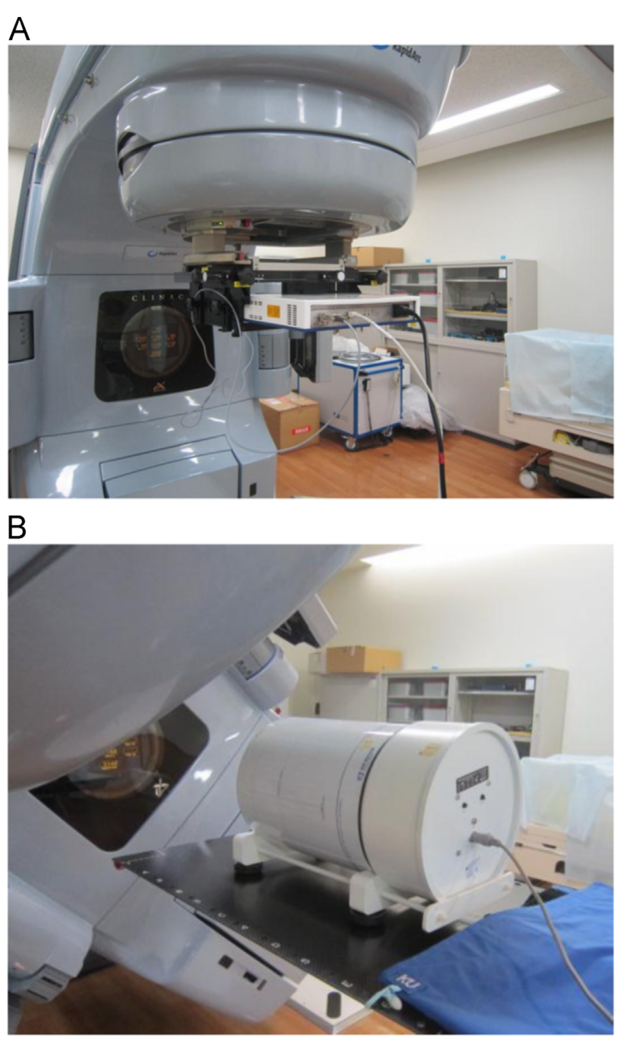

Fig. 1. (A) The Matrixx detector mounted on the gantry of a linear accelerator. (B) ArcCHECK setup on the treatment couch for measurement. (Color version of figure is available online.)

ArcCHECK with 3DVH—Measurement-guided system

The ArcCHECK consists of 1386 n-Si diodes ($0.8 \times 0.8\ \text{mm}^2$) arranged in a helical shape at 3 cm depth along the long-axis of a cylindrical phantom made of PMMA. The dimensions of the cylinder are 21 cm length and 21 cm diameter. The detectors are spaced 1 cm centre-to-centre and measure the exit and entrance dose during delivery. All measurements were performed using ArcCHECK (Fig. 1). The ArcCHECK 3DVH system requires the ArcCHECK measurements to be paired with the TPS-generated DICOM RT dose corresponding to the ArcCHECK measurement. All measured data were reconstructed as 3D dose distributions by 3DVH using the planned dose perturbation algorithm. ArcCHECK 3DVH does not require adjustments such as beam modeling for each linac system.

Open fields and MLC test patterns

First, the reconstructed dose distributions from COMPASS and ArcCHECK 3DVH were compared and checked against those measured with EDR2 film and MC calculated dose profiles using open fields (5×5, 10×10, $20 \times 20\ \text{cm}^2$), tongue and groove (T&G) pattern and IMRT test patterns (step, pyramid) formed with Millennium 120-leaf MLCs as shown in Fig. 2. The T&G pattern consists of 2 complementary parts. First, we irradiated one side then the other side.[10] All the dose distributions were compared along the arrowed line shown in Fig. 2 at a depth of 10 cm in a solid water phantom (RMI-457, GAMMEX, Germany) with a source-detector distance of 100 cm. The dose profiles from the EDR2 film were scanned and analyzed with a DD-system (R-tech, Tokyo, Japan).

Heterogeneous phantom

We compared the dose profiles on a heterogeneous phantom for the accuracy test in the heterogeneous region. MC simulations, TPS, and measurements were carried out for $10 \times 10\ \text{cm}^2$ open field with a constant source-to-surface distance of 100 cm for a 6 MV X-ray beam on a Varian Clinac iX linear accelerator. The TPS dose calculations were performed by Eclipse TPS version 8.9 (Varian Medical Systems, Palo Alto, CA) equipped with the AAA calculation algorithm. The monitor unit (MU) was 200 MU. In this study, we used 2 heterogeneous phantoms (Fig. 3). We obtained percentage-depth-dose (PDD) curves along the beam axis for each QA device in both models. The PDD curve was also obtained by means of an ionization chamber. The 0.125cc, PTW31002 (PTW, Freiburg, Germany) was used.

Clinical VMAT plans

We confirmed the accuracy of COMPASS and ArcCHECK 3DVH using clinical cases. We used single or 2-arc VMAT plans in the neck and mediastinum (Fig. 4). The X-ray energy and collimator angle were 6 MV and 45°, respectively. The treatment plans were generated by Eclipse TPS version 8.9. The prescribed doses for neck and mediastinum are 26 and 50 Gy for clinical target volume, respectively. For organ at risks, we used our hospital constraints.

MC simulation

To verify the accuracy of the COMPASS system and ArcCHECK 3DVH, the dose profiles and the dose distribution for neck and mediastinum plans were also calculated by the EGSnrc/BEAMnrc[11,12] and DOSXYZnrc[13] user-codes. Incident photon particles were derived from the treatment-head simulations at a 6 MV photon beam for a Varian Clinac iX. In MC calculations for neck and mediastinum plans, a voxel-based phantom was used. The voxel-based phantom was created by conversion of CT images into materials (air, lung, soft tissue, and bone) and mass densities. The MC dose distributions were also calibrated with the absorbed dose-to-water per MU and multiplied by the same MUs to the TPS for each treatment field. The calculation grid size was $2.5 \times 2.5 \times 2.5\ \text{mm}^3$ for the dose profile and $3.0 \times 3.0 \times 2.5\ \text{mm}^3$ for neck and mediastinum plans, respectively. The energy threshold and cutoff were AE = ECUT = 0.7 MeV and AP = PCUT = 0.01 MeV.