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Abstract: For the quality assurance (QA) of radiation treatment planning systems (RTPSs) and planning computed tomography (CT), a simple cylindrical phantom was developed. The phantom was constructed by using materials and geometries appropriate for the routine clinic setups. A Siemens Somatom HiQ CT, two-dimensional (2D) and three-dimensional (3D) RTPS and a linear accelerator Siemens Mevatron MD2 were used in this study.

The 2D and 3D RTPSs gave good results when compared to actual doses measured in the phantom. While the 3D system showed accuracy similar (-1.0% vs. –0.8%) to that of the 2D system for 6 MV and better accuracy (+1.4% vs. +2.2%) for 15 MV, but the improvement was not large.

The phantom described in this study provides simple measurements that enable one to check an RTPS calculation algorithm under inhomogeneous conditions and it gives accurate and reproducible results.

Key Words: Quality assurance, treatment planning system, phantom

Introduction

The process of radiation therapy is complex and involves many steps. At each step, comprehensive QA procedures are required to ensure the safe and accurate delivery of a prescribed radiation dose. This has led to the need to develop better QA tools that can be applied to RTPSs. An RTPS can contain a large number of errors when released for clinical use (1,2). Errors may be internal, such as new bugs introduced in software upgrades, or external, such as changes in the CT scanner (3). Routine QA is essential for ensuring that these problems are detected. Different authorities have released QA recommendations and guidelines for routine use of an RTPS (4-7). Numerous phantoms have been developed in order to compare doses calculated by planning systems to actual doses measured in phantoms. The commercially available calibration phantom RMI 467 (Gammex, Middleton, WI, USA) uses liquid and solid samples of various densities to determine CT density in Hounsfield Units. It has no holes for the ion-chamber to use under radiation. It can only be used for CT calibration. Howlett et al. used an anthropomorphic dose measurement phantom (8). They modified the phantom in order to use an ionization chamber and showed variations in the measured/calculated dose for a 3D system in heterogeneous conditions. They found the method very useful and recommended as one of the tests to use before implementing a new planning system. Craig et al. constructed a very complex and heavy phantom for a 3D RTPS (9). They found errors and limitations in the planning software and they stated that the QA of commercial treatment planning software is necessary. Phantoms for intensity-modulated radiation therapy (IMRT) patient treatment have been developed as well (10). They can be used with an ionization chamber, TLD or film to verify the patient plan. Kappas and Rosenwald proposed tests for inhomogeneity correction algorithms of RTPS as a part of the QA program (11). They indicated that tests should be included in the initial extensive validation of RTPS before starting clinical use and they should be repeated at regular intervals.

It is the medical physicist's responsibility to ensure the dose calculation accuracy of RTPS in the radiotherapy department. The aim of this study was to verify calculated data of RTPS under radiation using a custom-built phantom. So far, such data could only be checked under homogeneous density conditions using an RW3 solid water phantom (PTW, Germany) or a water phantom (Wellhöfer, Germany) in our department.

Materials and Methods

The phantom was designed to be both simple and from available materials. It consists of 14 cylindrical slabs of perspex 1 cm thick. Location holes for inhomogeneity cylinders and holes for the ionization chamber (PTW) were drilled as well (Figure 1). The inhomogeneity cylinders were 3 cm in diameter and made of various materials with densities equivalent to those of certain human body materials such as bone, tissue and lung. The simulating materials used in this study and their densities were polyoxymethylene (POM) (1.341 g/cm^3), Perspex (1.12 g/cm^3), polyethylene (PE) (0.94 g/cm^3), cork (0.204 g/cm^3), wood (0.375g/cm^3) and styrofoam (0.00125 g/cm^3).

The four location holes as measurement points (MPs) (Figure 2) for the chamber without a build-up cap were located 1.4 cm from the central rod in the phantom. The chamber axis was set perpendicular to the beam central axis and the point of measurement P_{eff} was positioned at the center of the phantom. The surface of the phantom was engraved with crosshairs so that, with the help of room lasers, the orientation of the phantom could be reproduced exactly. The phantom was scanned with inhomogeneity cylinders using the CT at the Radiology Department and the image data was transferred on-line into the planning system. The RTPS used in our department is the Multidata Decision Support System (DSS) version 2.4S (Multidata Systems Intl. Corp., St. Louis, MO). The DSS has the facility of reading CT images in the Hounsfield Unit (HU) of the pixel using a lookup table (Table 1) and it is converted into a density.

Three simple treatment setups, (1) G=0º, SSD=100 cm, (2) G=45º, SSD=90 cm and (3) G=0º to 90º arc, SSD=90 cm were used both for calculation and actual dose measurements. 20x10 cm^2 fields were used for all setups. The phantom, 0.6 cc 30001 farmer type ion chamber (PTW), Unidos electrometer (PTW) and Siemens Mevatron MD2 with dual photon energies (6 and 15 MV) were used for actual dose measurements. The ion chamber was placed in four MPs, one by one, within the phantom for three setups. Readings were corrected according to the IAEA 277 Report (12). Percent deviation defined as, Deviation (%) = ((Calculated dose/Measured dose)-1)x100, where Calculated dose = planning system result, Measured dose = dose obtained from the phantom under radiation.

Results

The relationship between densities is given in Figure 3. The physical densities (g/cm^3), CT densities (HU) and planning system lookup table densities matched well.

The percent deviation vs. MPs of 2D and 3D RTPSs for 6 and 15 MV photons are presented in Figures 4-7, respectively.

Average percent deviation and standard deviation of doses for two RTPS are listed in Table 2. The 2D and 3D systems showed an average of –0.8% and –1.0% for 6 MV, respectively, indicating underestimation of absorbed dose at the point of measurement and an average of +2.2% and +1.4% for 15 MV, respectively, indicating an overestimation of absorbed dose at the point of measurement. While the 3D system showed accuracy similar (-1.0% vs. –0.8%) to that of the 2D system for 6 MV and better accuracy (+1.4% vs. +2.2%) for 15 MV but the improvement was not large. Significantly, for the computerized calculations, an average percent deviation of 15 MV shows the higher deviation (less than 3%) for both systems (Figures 6 and 7). Further investigation is warranted.

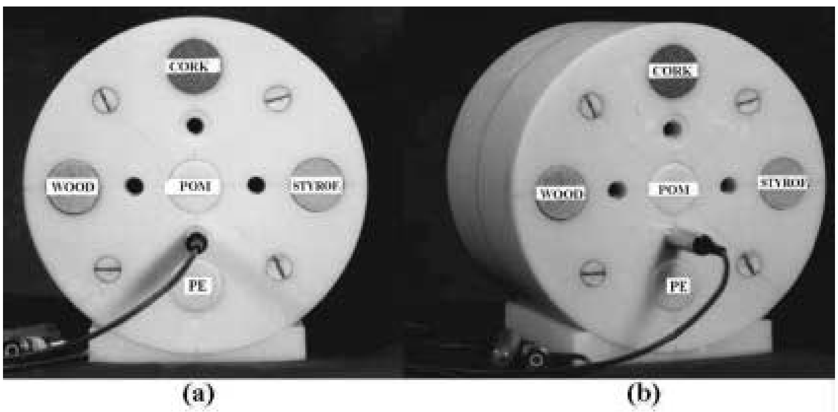

Figure 1. Front (a) and side (b) view of the phantom.

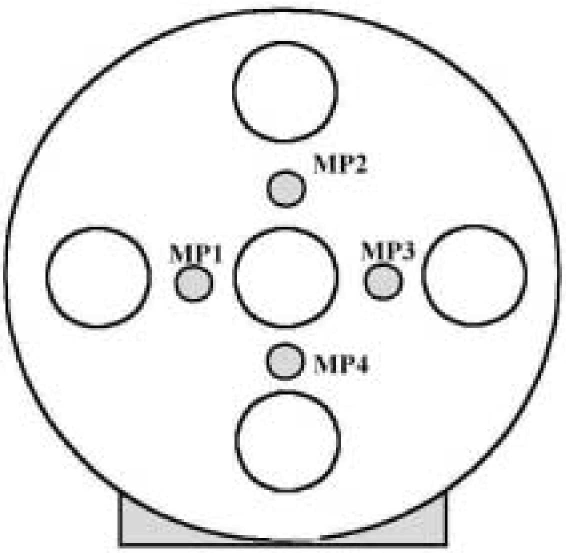

Figure 2. Schematic representation of the MPs in the phantom.

Table 1. CT density lookup table of Multidata DSS RTPS.

[CT_Density 1];				
Map of CT number to density				
density_qty=	4			
density_ct=	-1000,	0,	500,	1000,
density=	0.0,	1.0,	1.5,	2.00,

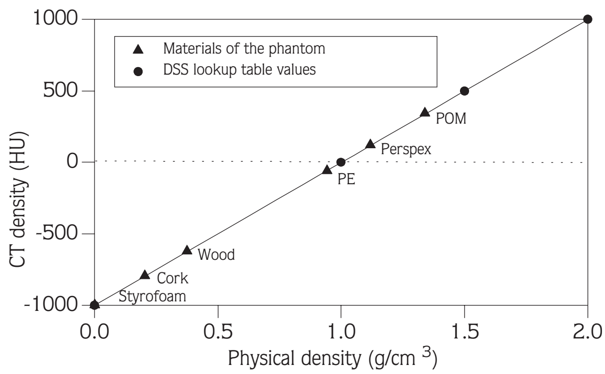

Figure 3. A comparison of physical density, CT density and DSS RTPS lookup table density values.

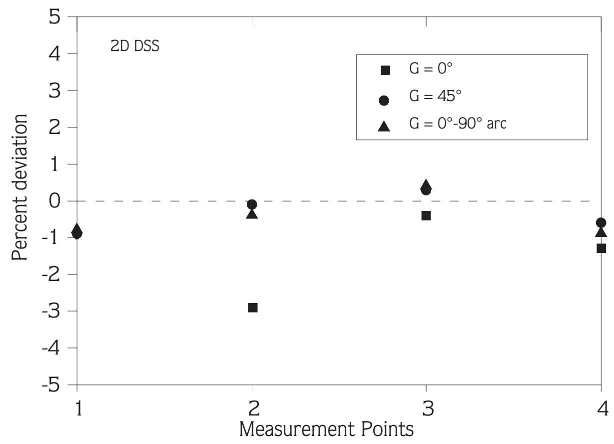

Figure 4. Percent deviation of doses for 2D DSS planning system for 6 MV.

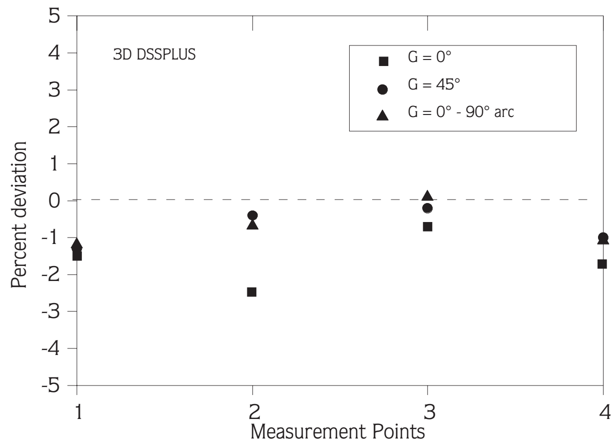

Figure 5. Percent deviation of doses for 3D DSSPLUS planning system for 6 MV.

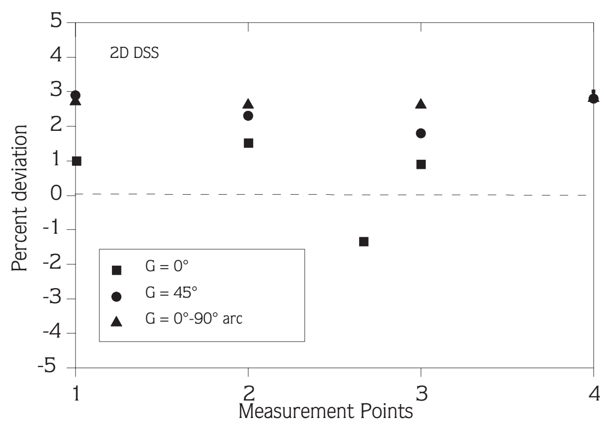

Figure 6. Percent deviation of doses for 2D DSS planning system for 15 MV.

Table 2. Average percent deviation and standard deviation of three setups.

	Average Percent Deviation			
	2D DSS		3D DSSPLUS	
Setups	6 MV	15 MV	6 MV	15 MV
1-G: 0°, SSD: 100cm	-1.4% ± 1.0	+1.6% ± 1.0	-1.6% ± 0.7	+0.9% ± 0.9
2-G: 45°, SSD: 90cm	-0.4% ± 0.6	+2.5% ± 0.5	-0.7% ± 0.5	+1.4% ± 0.3
3-G: 0° -90°, SSD: 90cm	-0.4% ± 0.6	+2.7% ± 0.1	-0.7% ± 0.6	+1.8% ± 0.1
Average	-0.8% ± 0.3	+2.2% ± 0.4	-1.0% ± 0.1	+1.4% ± 0.4

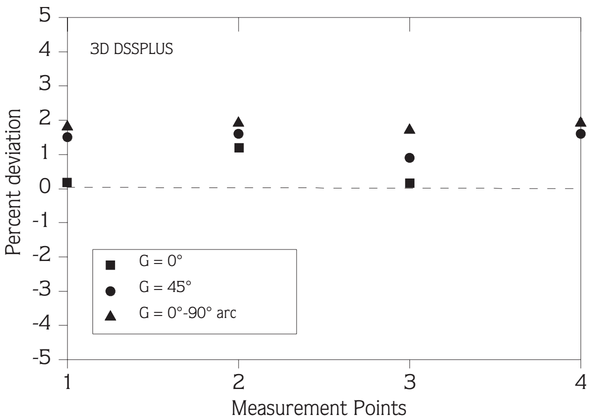

Figure 7. Percent deviation of doses for 3D DSSPLUS planning system for 15 MV

Discussion

Most computerized RTPSs currently use CT image data; these systems frequently use empirical formulae in computing correction factors for tissue inhomogeneities. Our phantom is quick and simple to construct and produces good and reproducible results to compare with RTPS for QA with the aid of an ion chamber.

There were no discrepancies found when comparing automatic CT density (HU) determination results obtained from CT, entering the densities manually and densities defined in the planning system lookup table. We can therefore assume that our planning CT and planning system are well calibrated.

In the comparison of the two treatment planning systems, no significant discrepancies were detected. The Multidata 2D and 3D planning systems produced similarly accurate results. The maximum deviation was 2.9%. The criterion of acceptability for inhomogeneity corrections for photon beam dose calculations is 3% (5-7). This would suggest that the data kernels of 2D DSS and 3D DSSPLUS RTPS are suitable for clinical use.

This phantom has been shown to be useful for the verification of treatment planning systems and might become an important tool for QA. When introducing a planning system, it is important that not only the basic data is checked, i.e. dose profiles and depth dose data, but also calculation algorithms.

Using this phantom, it is possible (a) to calibrate planning computers and planning CTs with regard to the Hounsfield units, (b) to evaluate calculated results from a planning system under consideration of density inhomogeneities like in a human body, and (c) to carry out the monthly checks of planning systems under defined and reproducible conditions.

The phantom described in this study provides simple measurements that enable one to check an RTPS calculation algorithm under inhomogeneous conditions.

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