Radiotherapy and Oncology 113 (2014) 272–278

Contents lists available at ScienceDirect

Radiotherapy and Oncology

journal homepage: www.thegreenjournal.com

Quality assurance

A multi-institutional dosimetry audit of rotational intensity-modulated radiotherapy

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ARTICLE INFO

Article history:
Received 12 May 2014
Received in revised form 4 November 2014
Accepted 6 November 2014
Available online 23 November 2014

Keywords:
Audit
IMRT
VMAT
Detector arrays

ABSTRACT

Background: Rotational IMRT (VMAT and Tomotherapy) has now been implemented in many radiotherapy centres. An audit to verify treatment planning system modelling and treatment delivery has been undertaken to ensure accurate clinical implementation.

Material and methods: 34 institutions with 43 treatment delivery systems took part in the audit. A virtual phantom planning exercise (3DTPS test) and a clinical trial planning exercise were planned and independently measured in each institution using a phantom and array combination. Point dose differences and global gamma index (γ) were calculated in regions corresponding to PTVs and OARs.

Results: Point dose differences gave a mean (±sd) of 0.1 ± 2.6% and 0.2 ± 2.0% for the 3DTPS test and clinical trial plans, respectively. 34/43 planning and delivery combinations achieved all measured planes with >95% pixels passing $\gamma < 1$ at 3%/3 mm and rose to 42/43 for clinical trial plans. A statistically significant difference in γ pass rates ($p < 0.01$) was seen between planning systems where rotational IMRT modelling had been designed for the manufacturer's own treatment delivery system and those designed independently of rotational IMRT delivery.

Conclusions: A dosimetry audit of rotational radiotherapy has shown that TPS modelling and delivery for rotational IMRT can achieve high accuracy of plan delivery.

Intensity Modulated Radiotherapy (IMRT), and more recently, Volumetric Modulated Arc Therapy (VMAT) and Tomotherapy are now implemented in many radiotherapy clinics [1]. Patient specific quality assurance for these rotational IMRT (RIMRT) techniques can be carried out using a second calculation with independent software or making a dose measurement on the linac, which has the added benefit of verifying the leaf motions, dose rates and, if applicable, gantry motion. ESTRO guidelines on the verification of IMRT have previously recommended that "more information is urgently needed about the accuracy of IMRT treatment delivery by having similar types of independent audit or inter-comparison programmes" as those published [2–5]. Since the commercial introduction of rotational IMRT capability on conventional linear accelerators, there has been a rapid uptake of VMAT and Tomotherapy, such that in 2010 in the United Kingdom (UK) around 30% of centres were already treating with some form of RIMRT. This led to the need for an audit of RIMRT with the following aims: independent verification of the implementation, investigation of the capability of the planning and delivery systems, assessment of whether each planning and delivery system had been optimised uniformly across each institution and credentialing for use of RIMRT in clinical trials.

This external dosimetry audit focussed entirely on rotational IMRT. Two previous studies included a few VMAT and Tomotherapy systems in IMRT audits [6,7] whereas others have been entirely static gantry IMRT [3,5,8,9]. This audit made use of a commercial detector array which allows the verification of dose in a large number of positions with immediate results. Our previous study, developed a methodology for using such a system in radiotherapy audits of rotational IMRT by comparing against other conventional systems of dosimetry such as film, ion chambers and alanine [10].

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http://dx.doi.org/10.1016/j.radonc.2014.11.015
0167-8140/

Materials and methods

All institutions in the UK who were already treating patients with a rotational IMRT technique or were ready to start treating by March 2013 were included in this audit. These comprised of 25 institutions with Varian linacs (Varian Medical Systems, Inc., Palo Alto, CA), 12 with Elekta linacs (Elekta AB, Stockholm, Sweden) and 6 with Helical Tomotherapy systems (Accuray-TomoTherapy, Madison, WI). The measurement system was the PTW Octavius II and seven29 array (PTW-Freiburg GmbH, Germany) and was chosen as it was robust, relatively easy to handle for transportation, straight forward to calibrate and gave analysis results typical of systems used in visited hospitals [11]. It has also been compared to different systems to prove its ability to detect errors [12]. This equipment was transported to each institution.

Plans

Each institution was asked to create two treatment plans. The first was a generic plan which had been designed for the purpose of comparing all rotational IMRT techniques, called the 3DTPS test [13], which is a virtual phantom with pre-delineated volumes (see Supplementary Fig. 1). The test included five PTVs and one OAR, each of which has different specified dose constraints per fraction (2.5 Gy: primary PTV2, 2.0 Gy: PTV3 and PTV5, and 1.5 Gy: PTV1 and PTV4, with maximum dose to the OAR less than 1.0 Gy). The plan was validated on each of the planning systems before the audit began and was designed to be challenging, and, as much as possible, equally so on each system, in terms of ability to achieve mandatory and optional dose constraints [13]. The second plan was chosen from amongst three different clinical sites of prostate and pelvic nodes (PPN), head and neck or breast from the pre-trial planning exercises of the national clinical trials portfolio (NCRI). The clinical plan was created on pre-delineated CT datasets using the local planning protocol. This also gave the institution the opportunity to fulfil part of the credentialing programme requirements to join the specific trial [14]. Both the 3DTPS plan and selected clinical plan had to be submitted and reviewed by the audit team before the visit could take place.

Verification plan creation

Each institution was provided with a set of CT scans of the Octavius II phantom. They were also provided with CT number to relative electron density and mass density calibration curves and were instructed to import the curve into their TPS where appropriate. This was not a mandatory step as the uncertainty was estimated to be within 0.5% [10]. Each institution was instructed to apply their normal procedure for couch correction; e.g. inserting or ignoring a couch structure in the planning system.

For the 3DTPS plan, institutions were given detailed instructions to ensure that the position of the dose distribution relative to the phantom was consistently reproduced, and thus the dose planes were measured in the same part of the plan from institution-to-institution. These were two coronal (horizontal) planes and a sagittal (vertical) plane (see Supplementary Fig. 1). The first coronal plane directly intersected PTV1, PTV2, PTV4 and PTV5. The second coronal plane was 4 cm posterior with respect to the first, and intersected the OAR, PTV1 and PTV3. A couch vertical shift was employed to transfer between the two setups and the same displacement for dose prediction calculations was made using the TPS. The sagittal plane intersected PTV2, PTV4, PTV5 and the OAR. A re-orientation of the phantom was employed for this third setup.

For the clinical trial plans, institutions were given similar instructions as to how to transfer and position the plan on the scan of the verification phantom. One coronal and one sagittal plane were measured, to sample the main PTVs and OARs (see Supplementary Fig. 2).

All verification plans were submitted for independent evaluation using the Visualization and Organization of Data for Cancer Analysis (VODCA) independent evaluation software version 4.3.0 [15]. For all plans, DICOM dose cubes were exported to be used for analysis.

Analysis

Analysis of each measured dose plane was made using the PTW Verisoft software (v 5.0). Absolute global gamma (γ) index calculations [16] were made which combine distance to agreement with a dose difference for every pixel in the plane against the 3D TPS dose distribution using the point dose spacing equal to that of the array (1 cm). A dose point, chosen in a high dose, low gradient region, was nominally set as 100% and a 20% threshold was applied to remove the low dose peripheral region. A range of gamma parameters were calculated, from 2 to 4% dose difference and from 2 to 4 mm distance to agreement. Differences between dose points measured in individual array cells and TPS predicted points were calculated, in regions relating to PTVs and OARs, as $(D_{meas} - D_{TPS}/D_{TPS})$. For the 3DTPS test six separate point dose locations were chosen, to sample different dose levels in the 3DTPS test. These were a central point in PTV2 and a point within PTV1 in the first coronal plane, and points in the PTV2 and PTV3 in the second coronal plane. In the sagittal orientation, a point was recorded in the PTV2 and in the OAR. For the clinical plans: Three to four separate point dose locations were chosen, to sample different dose levels in the PTVs and OARs, with location dependent on the clinical trial plan.

The TPS were grouped according to whether RIMRT modelling had been specifically designed for the manufacturer's own treatment delivery system (Type 1: Eclipse and HiArt) or had been designed to be independent of vendor or RIMRT delivery (Type 2: Monaco, OMP and Pinnacle). The data was also analysed by delivery system (Varian, Elekta and Tomotherapy).

Results

Measurements were made in 34 institutions in the UK with 43 different planning and delivery combinations. In total 215 dose planes were measured, and 413 point dose differences were calculated.

Fig. 1 shows the spread of the point dose differences in all points measured in the 3DTPS and clinical plans. The outliers were mainly measured in regions corresponding to OARs. For outliers corresponding to PTVs, the other PTVs measured in the plan were generally within 1sd of the mean for both the 3DTPS and the clinical plans.

For the gamma index calculations, Table 1 shows the mean pass rate for a range of γ parameters calculated per measured plane for the 3DTPS plan and for the clinical plans by site. The percentage of planes achieving at least 95% of $\gamma < 1$ are also shown. For the 3DTPS plan, 34/43(79.1%) of planning and delivery combinations achieved all measured planes with >95% pixels passing $\gamma < 1$ at 3%/3 mm with 12/43(27.9%) planning and delivery combinations passing all three measured planes with 100%, see Fig. 2. Combination 31 had only commissioned their system for simple prostate plans and therefore the 3DTPS was significantly more challenging than their routine plans (shown by the coronal plane pass rates of 85.5%(3DTPS) and 98.6%(prostate)). Repeat measurements were made in centres 29, 30, 31 and 41 (final results shown). In combination 25 and 41 two of the planes were >95%, and in 8 and 35 one plane was >95%. Apart from combination 29, all these results were from Monaco, Pinnacle and OMP TPS (Type 2). 27(62.7%) and