Technical Note

Application of a Comprehensive Treatment Planning Test for Credentialing Intensity-Modulated Radiotherapy and RapidArc in a TrueBeam Linear Accelerator Setup

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Abstract

An extended version of task group report (TG)-119 dosimetric tests was introduced and tested on the TrueBeam linear accelerator setup. Treatment plan results and quality assurance (QA) results of RapidArc (RA) and intensity-modulated radiotherapy (IMRT) were compared to understand the limitation and efficacy of the RA and IMRT system of the linear accelerator. Test structure sets were drawn on OCTAVIUS four-dimensional (4D) phantom computed tomography scan data for this study. We generated treatment plans based on the specified goal in the Eclipse™ treatment planning system using RA and IMRT in the study phantom. We used the same planning objectives for RA and IMRT techniques. Planar dose verification was performed using electronic portal imaging device and OCTAVIUS 4D phantom. The treatment log file was further analyzed using Pylinac (V2.4.0 (Open Source Code library available on Github, runs under Python programming language)) to compare the dosimetric outcome of RA and IMRT. Dose to the planning target volume (PTV) 1–5 and organ at risk (OAR) were analyzed in this study for the efficiency comparison of RA and IMRT. The primary objective was accomplished by adhering to the dose constraints associated with PTV 2 and the OAR. RA and IMRT also met the secondary objective. The tertiary goal of dose delivery to PTV 4 was met with RA but not IMRT. This study can be utilized to compare different institutions' planning and patient-specific QA (PSQA) procedures. The findings of this study were in line with the published works of the literature. A multi-institutional planning and delivery accuracy audit can be built using this structure and set of planning objectives having similar PSQA phantom. The TG-119 report incorporated test challenges that were combined in a single study set and a single plan. This reduces the complexity of performing the original TG-119 tests, whereas keeping the challenges as introduced in the TG-119 report. This study's planning and dosimetric results could be further utilized for dosimetry audit with any institute having a linear accelerator and OCTAVIUS 4D phantom for PSQA.

Keywords: Comprehensive quality assurance, log file analysis, task group-119, TrueBeam linac

Received on: 24-06-2022 **Review completed on: 29-03-2023** **Accepted on: 01-04-2023** **Published on: 29-06-2023**

Introduction

Radiotherapy planning and delivery methods have evolved significantly over the past decade. Using intensity-modulated radiotherapy (IMRT) and RapidArc (RA), a highly conformal dose distribution can be achieved while sparing normal tissues. Quality assurance (QA) is critical to ensure patient treatment repeatability and precision. A QA program is required for "high dose, high precision radiation" and is part of any radiotherapy program, according to task group (TG)-142.[1]

The National Cancer Research Institute in the UK formed the National Radiotherapy Trials QA group to coordinate QA activities in the clinical trials. As a result of this endeavor, a nine-module IMRT credentialing program was adopted by some centers across the UK. The audit consisted of a planning exercise, trial-specific questions, and procedure papers (treatment planning system [TPS] checks, fluence, and dose distribution verification).[2,3] An all-in-one structure set

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Website: www.jmp.org.in

DOI: 10.4103/jmp.jmp_56_22

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How to cite this article: Roy S, Sarkar B, Pradhan A. Application of a comprehensive treatment planning test for credentialing intensity-modulated radiotherapy and RapidArc in a TrueBeam linear accelerator setup. J Med Phys 2023;48:204-9.

was created to analyze the efficacy of RA and IMRT planning and execution, similar to the before-mentioned study.

Apart from EPID-based portal dosimetry (Portal Vision, Version 15.6, Varian, Palo Alto, CA, USA) and OCTAVIUS four-dimensional (4D) (PTW, Freiburg, Germany) software-based measurements, log files were inspected for QA purposes.[3-5] The log file analysis was done using Pylinac (V 2.4.0) and Python.

In some clinical conditions, a steep dose gradient may cause two concerns. First, the goal was unattainable due to multileaf collimator (MLC) and other mechanical limits, but much effort had been made in the TPS to achieve it. Second, a plan with a steep dose falloff was created by modifying the plan's parameters. However, its delivery accuracy was subjected to leaf positional accuracy and other similar constraints. To check the planning and execution limitation of IMRT, the TG-119 report had a few exercises which could check the credential of an IMRT delivery system.[6] This study included all TG-119 test tasks under a single study set. To compare the efficacy of RA and IMRT (dynamic MLC [dMLC]) for the same treatment goal as,[7] an IMRT/RA planning and QA test were developed and evaluated.

Cross-institutional data validation unavailability, unavailability of heterogeneous material inside the phantom and requirement of Octavius 4D phantom for PSQA were the limitations of our study.

Methods

This experiment was structured around a collection of therapeutically significant and geometrically simple volumes. This study introduced dip and step challenges, as was mentioned in Clark *et al*.[8] The test responded to the findings of Van Esch *et al*.[9] The TPS's capacity to administer doses to planning target volumes (PTVs) with an organ at risk (OAR) volume in the proximity was tested using a "dip" test. The "steps" were used to create the treatment plans with three different dose prescriptions, as usually encountered in a day-to-day clinical situation. Figure 1 depicts the steps and dips. These experiments were based on the AAPM TG-119 multitarget benchmarking test and were developed for rotating IMRT delivery systems.[6]

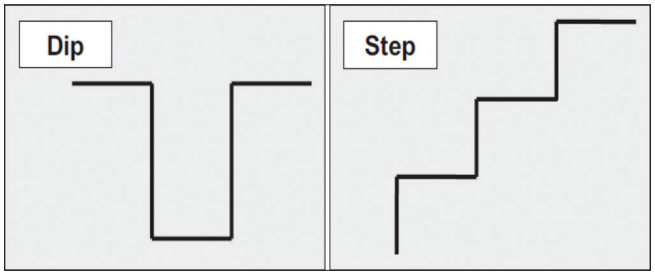

Figure 1: Step and dip effect, challenges which usually occurs in a treatment plan

In this study, we examined MLC position and relative dose levels in the transverse, coronal, and sagittal planes. We used an electronic portal imaging device (EPID) (Portal Vision, Varian, Palo Alto, CA, USA) for PSQA. The specification of the EPID device was as follows: amorphous silicon 1200 detector panel of active area 40 cm × 40 cm with 1190 × 1190 pixel arrays and pixel pitch of 0.336 mm. We also used an OCTAVIUS 4D phantom with a two-dimensional (2D) array for patient-specific QA. The 2D array was a matrix of 729 vented ionization chambers spaced 10 mm apart in a 27 cm × 27 cm array. Each chamber is 5 mm^3, with the effective measuring point located 7.5 mm below the detector array's surface. The array is placed within a cylinder-shaped, motorized polystyrene dummy (diameter and length 32 cm and 34.3 cm, respectively). The phantom was scanned in a 2.0 mm slice width with a computed tomography (CT) scanner (GE, Optima NMCT 640, Massachusetts, USA). CT data were imported into our TPS (Eclipse, V 15.6, Varian, Palo Alto, CA, USA). The SomaVision contouring system (Eclipse, V 15.5, Varian, Palo Alto, CA, USA) was used for creating the RT structure as per the recommended guidelines.[7]

To test if the dip and step effects could be achieved concurrently in both directions, the PTVs and OAR were positioned, as shown in Figure 2a and b. Five PTVs with varying dose levels surrounded a 20-mm diameter cylindrical OAR with a 1-cm gap between the PTV and the OAR. Figure 2a shows OCTAVIUS phantom with different structures in the

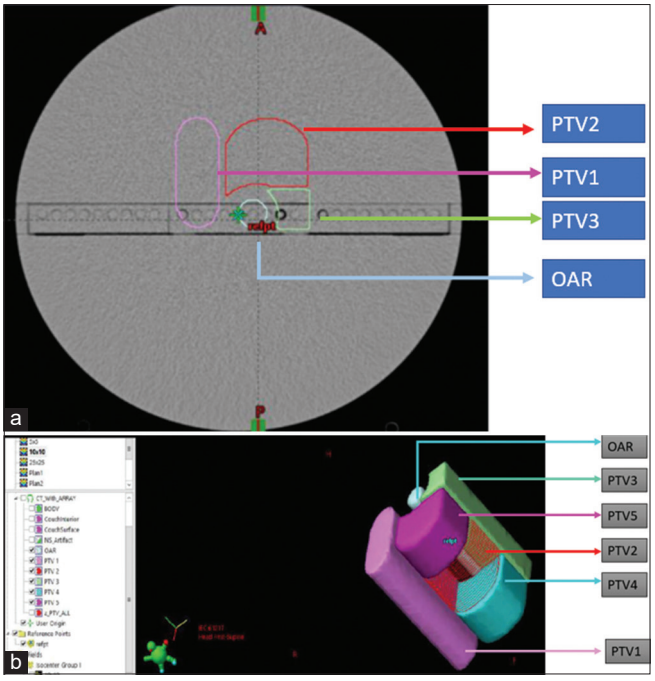

Figure 2: (a) OCTAVIUS 4D phantom CT scan with contours drawn for different PTVs and OAR in transverse axis, (b) 3D view of contours drawn for TG-119-modified challenge. 3D: Three-dimensional, 4D: Four-dimensional, CT: Computed tomography, PTV: Planning target volume, TG: Task group

transverse plane. Figure 2b shows three-dimensional view of the structure set drawn in the OCTAVIUS 4D phantom for the better understanding of the positions. PTV 2 had an anterior − posterior dimension of 50 mm and a length of 40 mm. PTV 4 and PTV 5 were installed superior and interior to PTV 2 in the same line. PTV 2 joined PTV 4 and PTV 5. PTV 3 was 120-mm long and positioned posterior to PTV 2. PTV 1 was a 30-mm wide by 120-mm long ellipse positioned adjacent to PTV 2 with a 5-mm gap. The dose prescription was 25 Gy for the principal aim, PTV 2, 20 Gy for PTV 3 and 5, and 15 Gy for PTV 1 and 4.

The primary planning purpose was to achieve PTV 2 planning constraints: a dose limitation of $D_{99\%}$>13.5 Gy (dose received by 99% of the volume) and maximum dose to OAR (D_{1cc}, i.e., dose received by one cc of volume) <10 Gy. The International Commission on Radiation Units and Measurements report 83 (ICRU-83) had advised that because of the increasing complexity of radiotherapy administration, the Dmax and Dmin dose for any structure to be changed with D2% and D98% dose, respectively.[10] ICRU-83 recommendations were considered in the present study objectives. Every objective outlined by Ezzel *et al*.[6] in the fundamental TG-119 test objectives could not be attained through a planning exercise. It could be inferred from the preceding statement that although a planning exercise may not be able to entirely meet the planning challenge, we can determine how closely the plan was able to meet its objectives. Due to this information, the test challenge was divided into three sections. During treatment planning, segment width, calculation grid, and dose fall-off-related parameters were set to the fundamental clinical values. One RA and one IMRT plan were created using the same planning objectives as mentioned below.

The primary aim must be achieved and the other goals must be prioritized:

1. The main purpose was to satisfy PTV 2 and OAR objectives
2. A secondary goal was to achieve PTV 1 and PTV 3
3. Attaining PTV 4 and PTV 5 constraints was a tertiary goal.

The homogeneity index (HI) of each PTV was compared between the plans to assess the dose changes. HI, according to ICRU 83, was defined as

$$HI = (D_2 - D_{98}) / D_{50} \qquad (1)$$

where $D_{2\%}$ was the dose received to last 2% of PTV, $D_{98\%}$ was the dose received by 98% of the PTV, and $D_{50\%}$ was the dose received by 50% of the PTV.[10]

Conformity index by Paddick[11] was defined as

$$CI_{Paddick} = \frac{TV^2{}_{PIV}}{TV \times V_{RI}} \qquad (2)$$

where TV_{PIV} was the volume of the PTV encompassed by prescription isodose, TV was the tumor volume, and V_{RI} was the total volume covered by the prescription isodose.

Glasgow *et al*.[12] defined IMRT factor as

$$\text{IMRT factor} = \frac{\text{total monitor units by all fields of a plan}}{\text{Dose per fraction of the treatment plan}} \qquad (3)$$

IMRT factor was a measure of the number of (MU/dose) required for the particular treatment plan.

The QA plan log files were evaluated using Python and Pylinac (V2.4.0) under various dose differences (DDs) and distance to agreement (DTA) criteria. Furthermore, the following data were taken from the log file (.bin file) for analysis: error in MLC average root mean square (RMS) for banks "A" and "B" individual field gamma passing (3% DD-3 mm DTA) and average gamma passing rate.

Results

All plans had a 2-mm CT slice thickness, which was the institution's typical scan resolution. These plans were delivered using Varian TrueBeam linear accelerator with millennium 120 MLCs. For RA, two arcs with 178 control points each were used. The IMRT plan had eight fields with the same isocenter position. IMRT had 1422.6 monitor units while RA had 765.7. Both IMRT (dMLC) and RA accomplished dose limitation to PTV 2 and OAR. The RA plan met the secondary aim of achieving dose to PTV 3 and PTV 1 but not the IMRT (dMLC) plan. Both RA and IMRT (dMLC) failed to achieve the tertiary goal for PTV 4 and 5.

Conformity index of 0.900 for RA and 0.799 for IMRT was found for the present study plans.[11]

RA and IMRT designs had HIs of 0.085 and 0.070. RAs conformity index outperformed IMRTs, yet its HI was nearly identical.

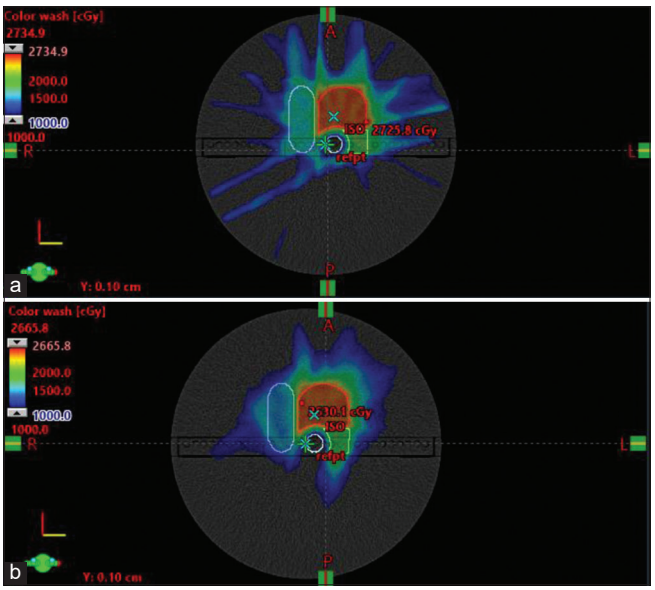

Figure 3: (a) The dose distribution of a IMRT (DMLC) plan on a transverse axis, showing dose spillage, (b) The dose distribution of a RA plan on a transverse axis, showing dose spillage. RA: RapidArc, DMLC: Dynamic multi-leaf collimator

Table 1: In the three-dimensional treatment planning system test, the dose constraints for each volume achieved for intensity-modulated radiotherapy

Volumes	Mean dose (goal) (Gy)	Mean dose (achieved) (Gy)	Minimum dose (goal) (Gy)	Minimum dose (achieved) (Gy)	Maximum dose (goal) (Gy)	Maximum dose (achieved) (Gy)
OAR	N/A	N/A	N/A	NA	$D_{1\ cm^3}$<10	10
PTV 1	15±0.5	16.01	$D_{99\%}$>13.5	15.04	$D_{10\%}$<16.5	16.68
PTV 2	25±0.5	26.06	$D_{99\%}$>22.5	24.51	$D_{10\%}$<26.5	26.56
PTV 3	20±0.5	20.82	$D_{99\%}$>18	19.01	$D_{10\%}$<22	21.38
PTV 4	15±1	17.43	$D_{99\%}$>13.5	15.49	$D_{10\%}$<18	19.16
PTV 5	20±1	21.28	$D_{99\%}$>18	20.04	$D_{10\%}$<22	21.97

OAR: Organ at risk, PTV: Planning target volume, N/A: Not available

Table 2: In the three-dimensional treatment planning system test, the dose constraints for each volume for RapidArc

Volumes	Mean dose (goal) (Gy)	Mean dose (achieved) (Gy)	Minimum dose (goal) (Gy)	Minimum dose (achieved) (Gy)	Maximum dose (goal) (Gy)	Maximum dose (achieved) (Gy)
OAR	N/A	N/A	N/A	N/A	$D_{1\ cm^3}$<10	9.5
PTV 1	15±0.5	15.09	$D_{99\%}$>13.5	13.82	$D_{10\%}$<16.5	15.63
PTV 2	25±0.5	25.34	$D_{99\%}$>22.5	23.59	$D_{10\%}$<26.5	25.84
PTV 3	20±0.5	20.1	$D_{99\%}$>18	18.53	$D_{10\%}$<22	20.56
PTV 4	15±1	16.77	$D_{99\%}$>13.5	14.4	$D_{10\%}$<18	18.23
PTV 5	20±1	20.49	$D_{99\%}$>18	18.98	$D_{10\%}$<22	21.1

OAR: Organ at risk, PTV: Planning target volume, N/A: Not available

Table 3: Gamma passing results for three-dimensional treatment planning system test plans for intensity-modulated radiotherapy (dynamic multileaf collimator) and RapidArc

Plan type	Passing criteria (DD and DTA)					
	OCTAVIUS 4D-based measurement			Portal dosimetry-based measurement (mm)		
	1% 1 mm	2% 2 mm	3% 3 mm	1% 1 mm	2% 2 mm	3% 3 mm
IMRT	39.3	72.5	91.4	82.4	97.4	99.6
RA	54.7	82.7	97.2	82.4	90.1	98.6

IMRT: Intensity-modulated radiotherapy, RA: Rapid arc, DTA: Distance to agreement, DD: Dose difference, 4D: Four dimensional

The IMRT factor for RA (4.254) was much lower than IMRT (7.903). Compared to IMRT, RA had substantially less dosage spillage to the phantom. Figure 3a and b describes the same pictorially. Tables 1 and 2 summarize achieved dose values for IMRT (dMLC) and RA for the test plans created for this study.

OCTAVIUS 4D phantom-based test and portal dosimetry verified and passed for both IMRT (dMLC) and RA test plans. The gamma passing criteria for PSQA were 1% DD 1mm DTA, 2% DD 2 mm DTA and 3%DD 3 mm DTA, respectively. Table 3 summarizes the QA results using the gamma index criteria, which include DDs and DTA parameters.[13] In case of EPID portal dosimetry, IMRT plan passing results were better compared to RA plan. However, OCTAVIUS 4D-based results were better for RA compared to IMRT. The standard gamma passing criteria for our institution were 3% DD and 3-mm DTA. The OCTAVIUS 4D-based measurement results were 91.4% and 97.2% for IMRT and RA, respectively, under 3% DD and 3-mm DTA. The results for EPID-based measurements under 3% DD and 3-mm DTA criteria for RA and IMRT were 99.6% and 98.6%, respectively. Although planar dose verification using EPID and OCTAVIUS 4D phantom was acceptable for both IMRT and RA, it is difficult to comment that one is superior to the other in planar dose verification results.

Table 4 summarizes the log file analysis results. The RA fields have superior gamma passing results than the IMRT scheme. All results available in Table 4 indicated MLC positional inaccuracy and gamma passing under different criteria. All results indicated MLC positional inaccuracy and gamma passing under different criteria. Based on unpaired *t*-test results, a statistically significant difference was found in gamma passing for RA compared to IMRT ($P = 0.01$). However, the MLC RMS average error for IMRT was significantly lower for IMRT compared to RA ($P = 0.01$).

Discussion

Many of the TG-119's lengthy test procedures were developed for forward IMRT and traditional EBRT. This comprehensive all-in-one module examination can be beneficial in evaluating the planning and delivery efficacy of any radiation department's RA and IMRT module of external beam radiotherapy. The test has been found to be a challenging plan and at least as hard to plan and verify as clinical trial plans (with breast, prostate with pelvic node, and head-and-neck being increasingly challenging). For this reason, we believe this test to be useful both for credentialing and commissioning. Log file analysis had shown to be a valuable method for identifying consistent

Table 4: Log file analysis of each field of the test plans (RapidArc and intensity-modulated radiotherapy)

Field	MLC RMS average (mm)	MLC RMS average A bank (mm)	MLC RMS average B bank (mm)	Percentage gamma passing for individual field	Average gamma value
RA field 1	0.25	0.24	0.25	99.97	0.01
RA field 2	0.25	0.26	0.24	99.96	0.01
IMRT field 1	0.13	0.14	0.12	99.84	0.02
IMRT field 2	0.13	0.15	0.12	99.49	0.03
IMRT field 3	0.15	0.14	0.16	99.50	0.03
IMRT field 4	0.12	0.12	0.16	99.85	0.03
IMRT field 5	0.18	0.23	0.14	98.70	0.09
IMRT field 6	0.20	0.26	0.14	99.53	0.04
IMRT field 7	0.25	0.25	0.25	99.13	0.09
IMRT field 8	0.27	0.32	0.22	99.42	0.05

IMRT: Intensity-modulated radiotherapy, RA: RapidArc, MLC: Multileaf collimator, RMS: Root mean square

variances between linear accelerator models and pinpointing the origin of any discrepancies found in RA/IMRT end-to-end testing.

Measured dose planes were analyzed with Verisoft (version 5.0) software (PTW, Freiburg, Germany). The calculations of the absolute global gamma index were performed by comparing the TPS dose distribution at a point dosage spacing equal to that of the array with the DTA for each pixel in the plane (1 cm). To get rid of the low-dose periphery, a 20% threshold was applied to a dose point selected from a high-dose, low-gradient zone. At a dose differential of 1%–3% and from a DTA of 1% to 3 mm, gamma parameters were computed.

With more complex dose distribution, achieving QA standards were critical. No matter how good a treatment plan was, if it would not meet the QA requirement, then it was of no use. For a low-gradient dose, it was found that over 30% of US cancer centers failed to deliver a dose distribution that agreed with their treatment plan within a tolerance of 7.5% DD or 4-mm distance to the agreement.[14] Complex radiotherapy treatment planning requires adjustments when PTVs and OARs were near together. Setting clear planning objectives were critical.

This test was expected to meet primary PTV 2 coverage and OAR saving targets. A secondary planning aim was set for PTV 1 and PTV 3. This combined the dip and steps experiments to see if the TPS could still give a heterogeneous dose distribution to multitarget volumes while minimizing radiation to the OAR. The last planning goal required the TPS to submit a plan that included PTV 4 and PTV 5. After achieving all preceding planning objectives, the TPS was tested to see if it could create plans with varying dose levels in superior inferior directions. The RA and IMRT plans met the primary planning goal.

The limitations of this study have been that the phantom used (OCTAVIUS 4D) was a homogeneous phantom. Therefore, no assessment can be made of the system's ability to correctly model IMRT/RA fields in the heterogeneous tissues. More research is needed to determine the optimal method of data analysis and whether it is better to use a single set of gamma parameters for the entire plan or to adjust the gamma parameters based on the volume of interest (e.g., a small percentage of DD and a small DTA for PTVs and a large percentage of DD and a large DTA for OARs). Clinics interested in performing this study will require OCTAVIUS 4D patient-specific QA phantom to perform this test. The structure set along with CT data will be shared in the future through GitHub to make it available to all users having OCTAVIUS phantom to perform this test. In future, some study structures can be created by taking these test challenges into consideration and making them uniformly applicable to any institute.

In this treatment planning test, RA planning outperformed IMRT planning to achieve the objectives. The planar fluence measurement using both OCTAVIUS 4D and EPID-based planar fluence measurements was acceptable and comparable to each other under 3% 3-mm gamma passing criteria which was the standard in our department.

Conclusions

This study showed that the rotational IMRT techniques in our department were safe and effective when they were used with clear and detailed planning instructions and goals. In the classical TG-119 test, there were a lot of complicated procedures. For IMRT and RA modules, this test module can be beneficial for checking the planning and delivery efficacy. Log file analysis of the trajectory log using Python was a valuable tool for further analysis of each field's performance. Our study's lack of multi-centre data comparability and heterogeneity unavailability was a limitation we intend to address in future.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

References

1. Klein EE, Hanley J, Bayouth J, Yin FF, Simon W, Dresser S, *et al.* Task Group 142 report: Quality assurance of medical accelerators. Med Phys 2009;36:4197-212.

2. McGarry CK, Agnew CE, Hussein M, Tsang Y, Hounsell AR, Clark CH. The use of log file analysis within VMAT audits. Br J Radiol 2016;89:20150489.
3. McGarry CK, Agnew CE, Hussein M, Tsang Y, McWilliam A, Hounsell AR, *et al.* The role of complexity metrics in a multi-institutional dosimetry audit of VMAT. Br J Radiol 2016;89:20150445.
4. Kerns JR, Childress N, Kry SF. A multi-institution evaluation of MLC log files and performance in IMRT delivery. Radiat Oncol 2014;9:176.
5. Sun B, Rangaraj D, Boddu S, Goddu M, Yang D, Palaniswaamy G, *et al.* Evaluation of the efficiency and effectiveness of independent dose calculation followed by machine log file analysis against conventional measurement based IMRT QA. J Appl Clin Med Phys 2012;13:3837.
6. Ezzell GA, Burmeister JW, Dogan N, LoSasso TJ, Mechalakos JG, Mihailidis D, *et al.* IMRT commissioning: Multiple institution planning and dosimetry comparisons, a report from AAPM Task Group 119. Med Phys 2009;36:5359-73.
7. Tsang Y, Ciurlionis L, Clark C, Venables K, NCRI Radiotherapy Trials Quality Assurance group. Development of a novel treatment planning test for credentialing rotational intensity-modulated radiotherapy techniques in the UK. Br J Radiol 2013;86:20120315.
8. Clark CH, Hussein M, Tsang Y, Thomas R, Wilkinson D, Bass G, *et al.* A multi-institutional dosimetry audit of rotational intensity-modulated radiotherapy. Radiother Oncol 2014;113:272-8.
9. Van Esch A, Bohsung J, Sorvari P, Tenhunen M, Paiusco M, Iori M, *et al.* Acceptance tests and quality control (QC) procedures for the clinical implementation of intensity modulated radiotherapy (IMRT) using inverse planning and the sliding window technique: Experience from five radiotherapy departments. Radiother Oncol 2002;65:53-70.
10. Hodapp N. The ICRU report 83: Prescribing, recording and reporting photon-beam intensity-modulated radiation therapy (IMRT). Strahlenther Onkol 2012;188:97-9.
11. Paddick I. A simple scoring ratio to index the conformity of radiosurgical treatment plans. Technical note. J Neurosurg 2000;93 Suppl 3:219-22.
12. Glasgow GP. Structural shielding design and evaluation for megavoltage X- and gamma-ray radiotherapy facilities. Med Phys 2006;33:3578.
13. Low DA, Dempsey JF. Evaluation of the gamma dose distribution comparison method. Med Phys 2003;30:2455-64.
14. Ibbott GS. The need for, and implementation of, image guidance in radiation therapy. Ann ICRP 2018;47:160-76.