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Original research article

Comparison of patient-specific intensity modulated radiation therapy quality assurance for the prostate across multiple institutions

Kazuki Kubo[a,b], *Hajime Monzen*[a,*], *Kohei Shimomura*[c], *Kenji Matsumoto*[d], *Tomoharu Sato*[e], *Mikoto Tamura*[a,d], *Kiyoshi Nakamatsu*[f], *Kentaro Ishii*[b], *Ryu Kawamorita*[b]

[a] *Department of Medical Physics, Graduate School of Medical Sciences, Kindai University, 377-2 Ohno-higashi, Osaka-sayama-shi, Osaka 589-8511, Japan*
[b] *Department of Radiation Oncology, Tane General Hospital, 1-12-21 Kujo-minami, Nishi-Ku Osaka-shi, Osaka 550-0025, Japan*
[c] *Department of Radiological Technology, Faculty of Medical Science, Kyoto College of Medical Science, 1-3 Imakita Sonobe-cho Oyama-higashi-machi, Nantan-shi, Kyoto 622-0041, Japan*
[d] *Department of Central Radiology, Kindai University Hospital, 377-2 Ohno-higashi, Osaka-sayama-shi, Osaka 589-8511, Japan*
[e] *Department of Radiation Oncology, Cancer Institute Hospital, 3-8-31, Ariake, Koto, Tokyo 135-8550, Japan*
[f] *Department of Radiation Oncology, Kindai University, 377-2 Ohno-higashi, Osaka-sayama-shi, Osaka 589-8511, Japan*

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ABSTRACT

Aim: To evaluate the success of a patient-specific intensity modulated radiation therapy (IMRT) quality assurance (QA) practice for prostate cancer patients across multiple institutions using a questionnaire survey.
Background: The IMRT QA practice involves different methods of dose distribution verification and analysis at different institutions.
Materials and Methods: Two full-arc volumetric modulated arc therapy (VMAT) plan and 7 fixed-gantry IMRT plan with DMLC were used for patient specific QA across 22 institutions. The same computed tomography image and structure set were used for all plans. Each institution recalculated the dose distribution with fixed monitor units and without any modification. Single-point dose measurement with a cylindrical ionization chamber and dose distribution verification with a multi-detector or radiochromic film were performed, according to the QA process at each institution.
Results: Twenty-two institutions performed the patient-specific IMRT QA verifications. With a single-point dose measurement at the isocenter, the average difference between

* *Corresponding author.*
E-mail address: hmon@med.kindai.ac.jp (H. Monzen).
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the calculated and measured doses was 0.5 ± 1.9%. For the comparison of dose distributions, 18 institutions used a two or three-dimensional array detector, while the others used Gafchromic film. In the γ test with dose difference/distance-to-agreement criteria of 3%–3 mm and 2%–2 mm with a 30% dose threshold, the median gamma pass rates were 99.3% (range: 41.7%–100.0%) and 96.4% (range: 29.4%–100.0%), respectively.

Conclusion: This survey was an informative trial to understand the verification status of patient-specific IMRT QA measurements for prostate cancer. In most institutions, the point dose measurement and dose distribution differences met the desired criteria.

1. Background

Intensity modulated radiation therapy (IMRT) and volume modulated arc therapy (VMAT) have been introduced at many institutions for the treatment of various cancers.[1–6] These techniques can create and shape more complicated dose distributions than conventional radiation therapy, which increases the complexity of treatment plans. Therefore, IMRT quality assurance (QA) verification is an important process employed to check the accuracy of IMRT plan dose calculations and detect clinically relevant errors in the radiation delivery, thereby ensuring the safety of patients and the fidelity of treatment.[7] However, the IMRT QA practice involves different methods of dose distribution verification and analysis at different institutions, because the institutions employ different measurement tools, IMRT planning systems, delivery systems, and IMRT/VMAT plans. As this study focuses on the consistency of IMRT QA measurement results, the planning and delivery systems used by each institution were limited to a single manufacturer. Furthermore, the IMRT/VMAT plans were created by the host center's experienced planner, using the same computed tomography (CT) image, structure set, and dose constraints. The patient-specific IMRT QA was performed with the same IMRT/VMAT plans being used across the institutions.

2. Aim

The purpose of this study was therefore to evaluate the achievements of a multiple-institution patient-specific IMRT QA practice for prostate cancer patients, with a questionnaire survey being used for this purpose.

3. Materials and methods

3.1. Survey

Twenty-two institutions participated in this study, with all of them also participating in a treatment planning seminar organized by the Japan Professional Accreditation Board for Radiotherapy Technologists (RTT) in 2017. All institutions used the Varian linac and treatment planning system (Eclipse: Varian Medical Systems, Inc., Palo Alto, CA, USA). Of the 22 institutions, 18 were already treating patients with IMRT and/or VMAT, and 4 were ready to start such treatments at that time.

Table 1 – Questionnaire items.

What is treatment machine?
Which is multi leaf collimator type, the millennium 120MLC or High definition 120 MLC?
What version of the treatment planning system?
Which is deliverable technique, IMRT or VMAT?
What is the electrometer?
What is the phantom?
What is dose distribution verification tool?
What is software to compare the dose distribution?
Which do you use for comparison of dose distribution, absorbed or relative dose?
Please specify the correlation factors regarding point dose measurement.
Please specify planned dose (mean and standard deviation) of IMRT/VMAT plan imported in your treatment planning system.
Please specify methodology of dose distribution verification in your institution.
Please specify verification results for last 10 patients in your institution.
What are planned and measured doses at isocenter in point dose measurement?
What are gamma pass rates at 3%–3 mm and 2%–2 mm with 30% threshold?

A 15-question internet-based survey on treatment equipment and patient-specific IMRT QA was designed to study the current state of practice in the 22 institutions. A questionnaire was emailed with a unique link to the survey describing the purpose of the project and emphasizing the confidentiality of the responses. The survey was split into two sections: treatment and measurement equipment, and patient-specific IMRT QA practice. The treatment and measurement equipment covered the treatment machine, MLC type, treatment planning system (TPS) version, electrometer, phantom, and dose distribution verification device, while the patient-specific IMRT QA practice included the methodology, correction factors, and the verification results for the last 10 patients, as shown in Table 1. The treatment equipment and delivery techniques used in each institution are listed in Table 2. Twelve centers used VMAT, 10 centers used IMRT, and no center used both.

3.2. IMRT and VMAT planning

To focus on the consistency of patient-specific IMRT QA measurements between institutions, IMRT and VMAT plans were

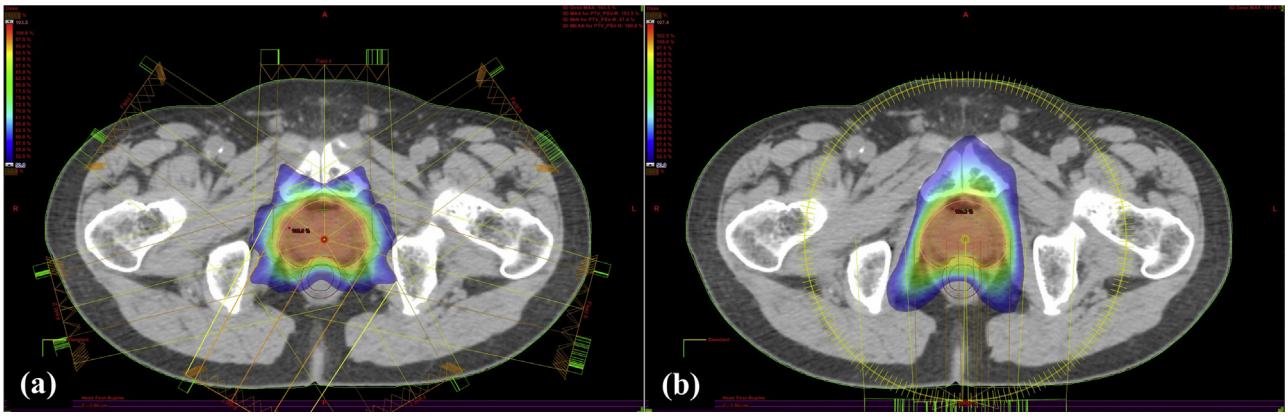

Fig. 1 – Dose distributions of (a) 7 fixed-gantry IMRT and (b) 2 full arcs VMAT plans created by the host center's experienced planner.

Table 2 – List of equipment and delivery techniques in the 22 institutions.

Institution	Machine	MLC type	Modality	TPS version
1	Novalis Tx	HD120	VMAT	10
2	Novalis Tx	HD120	IMRT	13
3	Clinac iX	Millennium120	VMAT	11
4	TrueBeam STx	HD120	VMAT	13
5	Clinac iX	Millennium120	IMRT	11
6	Clinac iX	Millennium120	VMAT	11
7	Trilogy	Millennium120	IMRT	13
8	Clinac iX	Millennium120	IMRT	13
9	Clinac iX	Millennium120	IMRT	11
10	Novalis Tx	HD120	VMAT	11
11	Novalis Tx	HD120	IMRT	10
12	Trilogy	Millennium120	IMRT	13
13	TrueBeam	Millennium120	VMAT	13
14	Clinac iX	Millennium120	IMRT	8
15	TrueBeam STx	HD120	VMAT	13
16	Clinac iX	Millennium120	IMRT	13
17	TrueBeam	Millennium120	VMAT	13
18	TrueBeam	Millennium120	IMRT	13
19	TrueBeam	Millennium120	VMAT	13
20	TrueBeam STx	HD120	VMAT	13
21	Clinac 21EX	Millennium120	IMRT	15
22	TrueBeam	Millennium120	VMAT	13

generated by an experienced planner working in the host institution. Each IMRT and VMAT plan for the different types of MLC (Millennium 120 and High-definition 120 MLCs) were created with the same CT image and structure set acquired from a patient with prostate cancer. Beam settings were 7 fixed-gantry and 10 MV photons in the IMRT plan, and 2 full arcs (181° to 179°; clockwise and counterclockwise) and 10 MV photons in the VMAT plan. Optimization processes were performed with the same dose constraints for both the IMRT and VMAT plans, as shown in Table 3. The prescribed dose was 78 Gy in 39 fractions for the mean dose to the planning target volume. Fig. 1 shows the dose distributions for the IMRT and VMAT plans. The plans including the CT images and structures in the DICOM-RT format were distributed to the 22 institutions.

Table 3 – Dose constraints for the IMRT and VMAT plans.

Structure	Dose metric	Dosimetric goal
PTV	D95%	≥75.6 Gy
	D98%	≥74.1 Gy
	D50%	= 78.0 Gy
	D2%	≤80.0 Gy
Rectum	V70Gy	<20.0%
	V50Gy	≤45.0%
	D2%	≤80.0 Gy
Bladder	V70Gy	≤25.0%
	V50Gy	≤50.0%
	D2%	≤80.0 Gy
Femoral head	D2%	≤50.0 Gy

3.3. *Patient-specific IMRT measurements at the isocenter*

The dose distributions were recalculated with fixed monitor units and without any modification to create the verification plan for the phantom at each institution, with each institution's treatment planning system being used for this purpose.

Point dose measurement was performed with a 0.6 cm^3 ionization chamber, which was calibrated in terms of absolute dose to water traceable to a secondary standard. The measurement was performed with all fields irradiating the institution's water equivalent phantom using the planned gantry and collimator rotations. The measurement point was positioned at the isocenter. The collecting volume of the ionization chamber was contoured on the institution's water equivalent phantom CT image, and the planned dose was defined as the average dose in the volume. The measured dose was corrected by the daily output factor, to reduce the effects of daily linac output variations and differences between the phantom and liquid water.

The measured dose distributions were compared with the dose distributions calculated by the treatment planning system, with the measuring system and methodology following the usual practice at each institution. A global gamma test including 3% dose differences and a 3-mm distance-to-agreement criterion was performed with a 30% threshold, as is commonly used to reduce over-sensitivity to low dose points and measurement uncertainty.[8] Additionally, a stricter

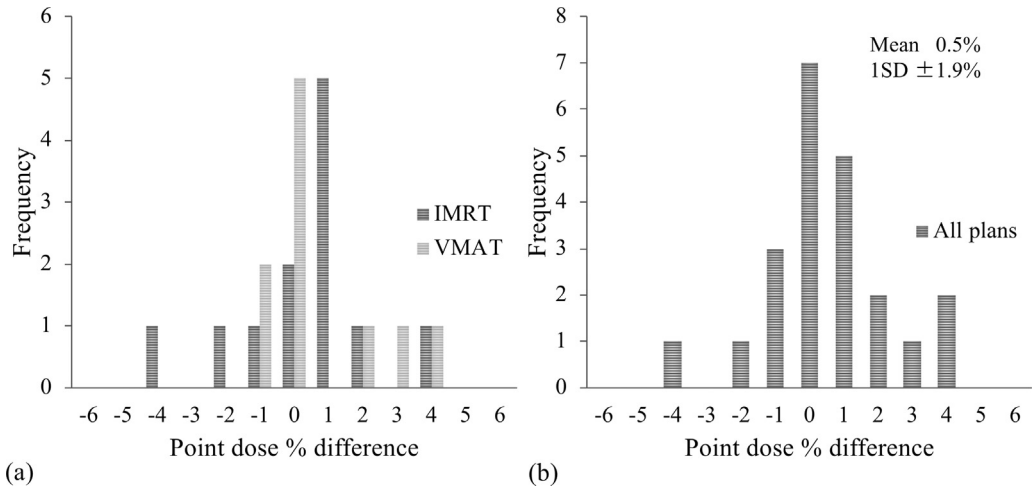

Fig. 2 – The point dose differences between the measured and planned doses for (a) IMRT versus VMAT plans, (b) all plans.

2%–2 mm criterion was used for comparisons between different measurement tools.

4. Results

Twelve institutions used an I'mRT phantom (IBA Dosimetry, Louvain-La-Neuve, Belgium), six institutions used an RT-3000-NEW phantom (R-TEC.INC, Nagano, Japan), two institutions used an ArcCHECK phantom (Sun Nuclear Corporation, Melbourne, FL, USA), and two institutions used an RW3 phantom (PTW Freiburg, Freiburg, Germany). With the point dose measurements, the mean percentage dose difference between the measured and planned doses was 0.49 ± 1.86% (mean ± one standard deviation [1SD]). Fig. 2 shows the spread of the point dose differences over all institutions. Larger dose differences over 2% were observed in six institutions. Four of these were institutions that had not completed the commissioning process to start using IMRT/VMAT in clinical practice (institution number 8, 11, 17, and 19 in Table 4). The other two showed positive or negative error trends, which were similar to the verification results for the last 10 patients measured at their institution as shown in Table 4 (institution number 12 and 20). The mean percentage dose difference was 0.24 ± 1.22% in the 18 institutions that had started treatment with IMRT/VMAT.

For dose distribution measurement, six institutions used a Delta4 (ScandiDos, Uppsala, Sweden), five institutions used an ArcCHECK, four institutions used Gafchromic EBT film (Ashland, Covington, KY, USA), five institutions used MapCHECK2 (Sun Nuclear Corporation), and two institutions used the Dolphin and COMPASS system (IBA Dosimetry, Louvain-La-Neuve, Belgium). In the comparison of measured and planned dose distributions, the median gamma pass rates were 96.4% (range: 29.4%–100.0%) and 99.3% (range: 41.7%–100.0%) for the passing criteria of 2%–2 mm and 3%–3 mm, respectively. Fig. 3 shows histograms of the gamma pass rate results at passing criteria of 3%–3 mm and 2%–2 mm.

5. Discussion

To focus on the consistency of patient-specific IMRT QA results between institutions, this questionnaire survey was performed only for Varian machines and Eclipse users, and the same IMRT/VMAT plans were prepared across all institutions. We found that the results of point dose measurements and dose distribution verifications were consistent across most institutions in Japan, even though the institutions employed different measurement tools. Some institutions were also found to show outlying values.

The results reported in this study were obtained using only an online survey. In contrast, in multi-institutional clinical trials, a phantom is generally sent to the participating institutions. The phantom generally contains some structures, and the treatment plan is created by each institution for external audit.[9,10] Jornet et al. studied multi-center comparisons of IMRT dose planning and pretreatment verification. They found that all centers fulfilled the dosimetric goals, but that plan quality and delivery complexity were heterogenous and uncorrelated, depending on the manufacturer and planner's methodology.[11] Jurado-Bruggeman et al. also observed similar results in VMAT dose planning across multiple centers.[12] McGarry et al. observed a stronger correlation between plan complexity and gamma pass rate with Varian linear accelerators in a multi-institutional dosimetry audit of VMAT.[13] Therefore, validation of the consistency of patient-specific IMRT QA verification between institutions should be performed using the same IMRT/VMAT plan. In this study, the participating institutions were required to re-calculate the plans to create a verification plan with their own phantom. Some studies showed highly similar beam data with some small variations in standard field size and treatments across multiple linear accelerators from the same manufacturer.[14,15] This disregards the variations caused by beam data between different machines by the same manufacturer. Different verification tools may show different gamma pass rates,[16] but our results did not show a tendency to depend on the verification tools, even though the criterion of 2%–2 mm was used to

Table 4 – The point dose verification results for the last 10 patients measured at their institution and results in the present study.

Institution	Errors of point dose verification for the last 10 patients (%)										Present study (%)
	1	2	3	4	5	6	7	8	9	10	
1	−0.3	−0.2	−0.5	−0.3	−0.3	−0.2	0.2	−0.6	0.1	−0.5	−0.6
2	0.1	0.0	−0.1	0.0	0.6	0.4	0.2	0.8	0.0	0.5	0.5
3	−2.4	−0.7	0.5	−1.4	0.8	1.7	−2.1	−0.5	0.3	0.1	−1.5
4	−0.3	0.4	0.8	0.2	0.3	0.1	−0.3	−0.3	0.0	−0.5	0.3
5	0	0.1	−0.8	−0.9	−0.7	−0.7	−0.7	−0.7	−0.2	−0.6	1.2
6	−1.6	−0.5	−0.8	−0.9	−0.6	−0.6	−0.9	0.5	−0.5	−0.8	0.1
7	1.3	0.7	1.4	1.3	1.6	1.2	1.0	1.5	1.8	1.3	1.2
8	No data										2.2
9	0.3	−1.2	−0.7	−1.7	−1.1	−1.3	0.0	−0.3	−0.1	−1.1	−1.4
10	0.2	1.1	0.5	0.2	1.2	1.4	0.4	0.8	0.4	0.5	0.1
11	3.4	2.9	1.8	3.4	2.2	No data					−3.7
12	0.9	0.2	−0.7	−0.7	−0.5	−1.4	−1.4	−1.8	−1.8	−0.4	−2.4
13	−0.7	−0.1	0.0	−0.5	−0.4	−0.2	−0.7	0.4	−0.7	0.0	−0.3
14	−0.2	0.4	0.3	−0.3	−0.3	0.0	0.1	−0.3	0.8	−0.3	0.9
15	Unanswered										0.1
16	0.9	No data									0.8
17	No data										4.3
18	0.2	0.2	0.2	0.2	0.2	−0.1	1.5	1.5	0.5	1.3	1.9
19	No data										3.8
20	2.2	1.3	1.5	0.9	0.9	1.9	2.7	1.6	0.2	3.3	2.6
21	0.3	1.2	−0.9	−0.4	0.3	0.1	−0.4	1.4	0.2	0.2	−0.3
22	Unanswered										1.1

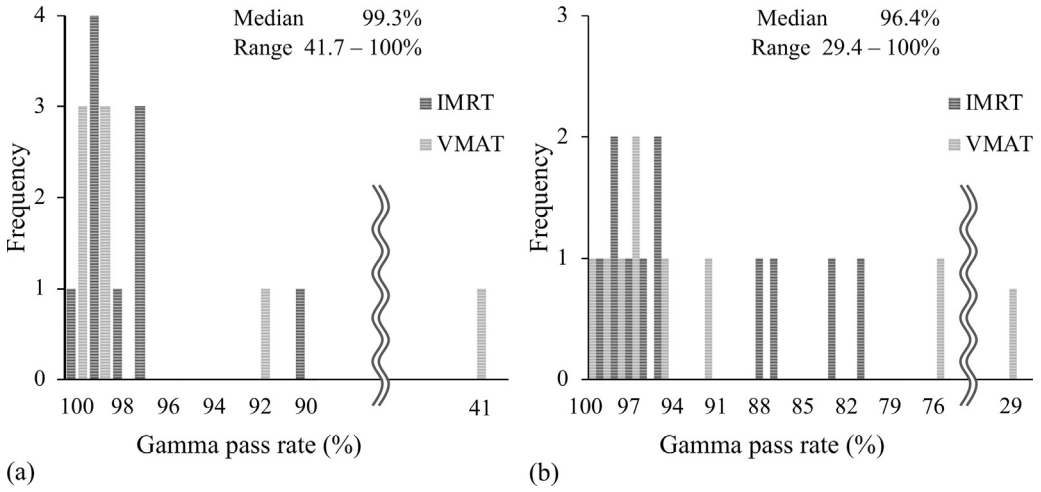

Fig. 3 – Histograms of the gamma pass rate at passing criteria of (a) 3%–3 mm and (b) 2%–2 mm.

detect subtle and systematic errors. In addition, there was no tendency related to different linacs or TPS versions in measurement results in this study. Our results, therefore, reflect the patient-specific IMRT QA accuracy across multiple institutions in Japan.

Very small variations were observed in the point dose measurements. The instructions and guidelines for patient-specific IMRT QA measurements might be maintained in Japan, and a standardized process is performed in most institutions. Similarly, the results of the dose distribution verification were almost identical, although two institutions showed a gamma pass rate of approximately 90% for the 3%–3 mm criterion; however, both institutions showed good agreement with the other institutions in the point dose measurement. Of these two institutions, one used ArcCHECK and the other used Gafchromic film for dose distribution verification. Generally, ArcCHECK provides high reproducibility and stability for planning verification.[17] Errors related to preparation or the measurement process would affect the results. Film dosimetry requires efficient correcting for film inhomogeneity and inter-scan variability,[18] but the correction of these effects might have been insufficient. The lowest gamma pass rates in dose distribution verification were observed at the institution which had not completed the commissioning process to start using IMRT/VMAT in clinical practice. This questionnaire survey can improve patient-specific IMRT QA quality of each institution in the feedback information.

This study has some limitations. The information of the MLC data, such as the leaf end transmission and inter-and-intra leaf transmission, was not requested from the

institutions participating in this study, and these data have the greatest impact on dose calculation in IMRT and VMAT. And the target spot size is also one of the factors to affect dose distribution. Furthermore, measurement error caused by mechanical errors, such as misalignment of wall-mounted lasers, cannot be detected from this survey. The gamma pass rate is a very indirect measure which can affect the outcome such as the algorithm settings used in computing the dose distribution, the detector system, the precision used for phantom positioning, etc.

6. Conclusion

This survey was an informative trial to understand the status of the verification of patient-specific IMRT QA measurements for prostate cancer. In most institutions, the point dose measurement and the dose distribution differences met the desired criteria.

Declarations of interest

None.

Conflict of interest

None declared.

Financial disclosure

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REFERENCES

[1]. Fogliata A, Clivio A, Nicolini G, et al. Intensity modulation with photons for benign intracranial tumors: a planning comparison of volumetric single arc, helical arc and fixed gantry techniques. *Radiother Oncol* 2008;**89**:254–62, http://dx.doi.org/10.1016/j.radonc.2008.07.021.

[2]. Lagerwaard FJ, van der Hoorn EA, Verbakel WF, et al. Whole-brain radiotherapy with simultaneous integrated boost to multiple brain metastases using volumetric modulated arc therapy. *Int J Radiat Oncol Biol Phys* 2009;**75**:253–9, http://dx.doi.org/10.1016/j.ijrobp.2009.03.029.

[3]. Bertelsen A, Hansen CR, Johansen J, et al. Single arc volumetric modulated arc therapy of head and neck cancer. *Radiother Oncol* 2010;**95**:142–8, http://dx.doi.org/10.1016/j.radonc.2010.01.011.

[4]. Scorsetti M, Navarria P, Mancosu P, et al. Large volume unresectable locally advanced non-small cell lung cancer: acute toxicity and initial outcome results with rapid arc. *Radiat Oncol* 2010;**5**:94, http://dx.doi.org/10.1186/1748-717X-5-94.

[5]. Wolff D, Stieler F, Welzel G, et al. Volumetric modulated arc therapy (VMAT) vs serial tomotherapy, step-and-shoot IMRT and 3D-conformal RT for treatment of prostate cancer. *Radiother Oncol* 2009;**93**:226–33, http://dx.doi.org/10.1016/j.radonc.2009.08.011.

[6]. Benthuysen LV, Hales L, Podgorsak MB. Volumetric modulated arc therapy vs. IMRT for the treatment of distal esophageal cancer. *Med Dosim* 2011;**36**:404–9, http://dx.doi.org/10.1016/j.meddos.2010.09.009.

[7]. Miften M, Olch A, Mihailidis D, et al. Tolerance limits and methodologies for IMRT measurement-based verification QA: Recommendations of AAPM Task Group No. 218. *Med Phys* 2018;**45**:e53–83, http://dx.doi.org/10.1002/mp.12810.

[8]. Shimohigashi Y, Araki F, Maruyama M, et al. Evaluation of a single scan protocol for radiochromic film dosimetry. *J appl Clin Med Phys* 2015;**16**:412–24, http://dx.doi.org/10.1120/jacmp.v16i2.5226.

[9]. Molineu A, Hernandez N, Nguyen T, et al. Credentialing results from IMRT irradiations of an anthropomorphic head neck phantom. *Med Phys* 2013;**40**:022101, http://dx.doi.org/10.1118/1.4773309.

[10]. Nakamura M, Minemura T, Ishikura S, et al. An on-site audit system for dosimetry credentialing of intensity-modulated radiotherapy in Japanese Clinical Oncology Group (JCOG) clinical trials. *Phys Med* 2016;**32**:987–91, http://dx.doi.org/10.1016/j.ejmp.2016.07.002.

[11]. Jornet N, Carrasco P, Beltrán M, et al. Multicentre validation of IMRT pre-treatment verification: Comparison of in-house and external audit. *Radiother Oncol* 2014;**112**:381–8, http://dx.doi.org/10.1016/j.radonc.2014.06.016.

[12]. Jurado-Bruggeman D, Hernández V, Sáez J, et al. Multi-centre audit of VMAT planning and pre-treatment verification. *Radiother Oncol* 2017;**124**:302–10, http://dx.doi.org/10.1016/j.radonc.2017.05.019.

[13]. McGarry CK, Agnew CE, Hussein M, et al. The role of complexity metrics in a multi-institutional dosimetry audit of VMAT. *Br J Radiol* 2016;**89**:20150445, http://dx.doi.org/10.1259/bjr.20150445.

[14]. Watts RJ. Comparative measurements on a series of accelerators by the same vendor. *Med Phys* 1999;**26**:2581–5.

[15]. Beyer GP. Commissioning measurements for photon beam data on three TrueBeam linear accelerators, and comparison with Trilogy and Clinac 2100 linear accelerators. *J Appl Clin Med Phys* 2013;**14**:4077, http://dx.doi.org/10.1120/jacmp.v14i1.4077.

[16]. Hussein M, Rowshanfarzad P, Ebert MA, et al. A comparison of the gamma index analysis in various commercial IMRT/VMAT QA systems. *Radiother Oncol* 2013;**109**:370–6, http://dx.doi.org/10.1016/j.radonc.2013.08.048.

[17]. Li G, Zhang Y, Jiang X, et al. Evaluation of the ArcCHECK QA system for IMRT and VMAT verification. *Phys Med* 2013;**29**:295–303, http://dx.doi.org/10.1016/j.ejmp.2012.04.005.

[18]. Marrazzo L, Zani M, Pallotta S, et al. GafChromic® EBT3 films for patient specific IMRT QA using a multichannel approach. *Phys Med* 2015;**31**:1035–42, http://dx.doi.org/10.1016/j.ejmp.2015.08.010.