QUANTITATIVE DATA TO SHOW EFFECTS OF GEOMETRIC ERRORS AND DOSE GRADIENTS ON DOSE DIFFERENCE FOR IMRT DOSE QUALITY ASSURANCE MEASUREMENTS

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To quantitatively evaluate how setup errors in conjunction with dose gradients contribute to the error in IMRT dose quality assurance (DQA) measurements. The control group consisted of 5 DQA plans of which all individual field dose differences were less than ±5%. On the contrary, the examination group was composed of 16 DQA plans where any individual field dose difference was larger than ±10% even though their total dose differences were less than ±5%. The difference in 3D dose gradients between the two groups was estimated in a cube of 6 × 6 × 6 mm^3 centered at the verification point. Under the assumption that setup errors existed during the DQA measurements of the examination group, a three dimensional offset point inside the cube was sought out, where the individual field dose difference was minimized. The average dose gradients of the control group along the x, y, and z axes were 0.21, 0.20, and 0.15 $cGy \cdot mm^{-1}$, respectively, while those of the examination group were 0.64, 0.48, and 0.28 $cGy \cdot mm^{-1}$, respectively. All 16 plans of the examination group had their own 3D offset points in the cube. The individual field dose differences recalculated at the offset points were mostly diminished and thus the average values of total and individual field dose differences were reduced from 3.1% to 2.2% and 15.4% to 2.2%, respectively. The offset distribution turned out to be random in the 3D coordinate. This study provided the quantitative data that support the large individual field dose difference mainly stems from possible geometric errors (e.g., random setup errors) under the influence of steep dose gradients of IMRT field.

Keywords: IMRT DQA, setup error, dose gradient, dose difference

1. INTRODUCTION

The justification, philosophy, and requirements of an Intensity-modulated radiation therapy quality assurance (IMRT QA) program were given in the American Association of Physicists in Medicine (AAPM) and European Society for Radiotherapy and Oncology (ESTRO) reports [1−3]. Point dose measurements using an ion chamber embedded into a phantom have been commonly practiced for IMRT dose verification [4−8]. During this procedure, one could possibly detect errors in a treatment planning system (TPS), measurement process and IMRT delivery [4, 6, 8]. Therefore, how the errors can be identified and whether the errors can be adequately detected are clinically significant issues [4-12] and they have been extensively addressed in the literature [2, 3, 8−12]. Recently values of ±4% to ±5% difference between measured and calculated doses were set to be a confidence limit for IMRT commissioning that could be achievable when ionization chamber measurements for the same mock structures were performed by multi-institutions [13−15].

In our institution, the value of ±4% difference between measured and calculated *total* doses has been established as a tolerance level for DQA measurements using an ion-chamber. This value is comparable to the tolerance of multi-center studies [13, 14]. Most of our

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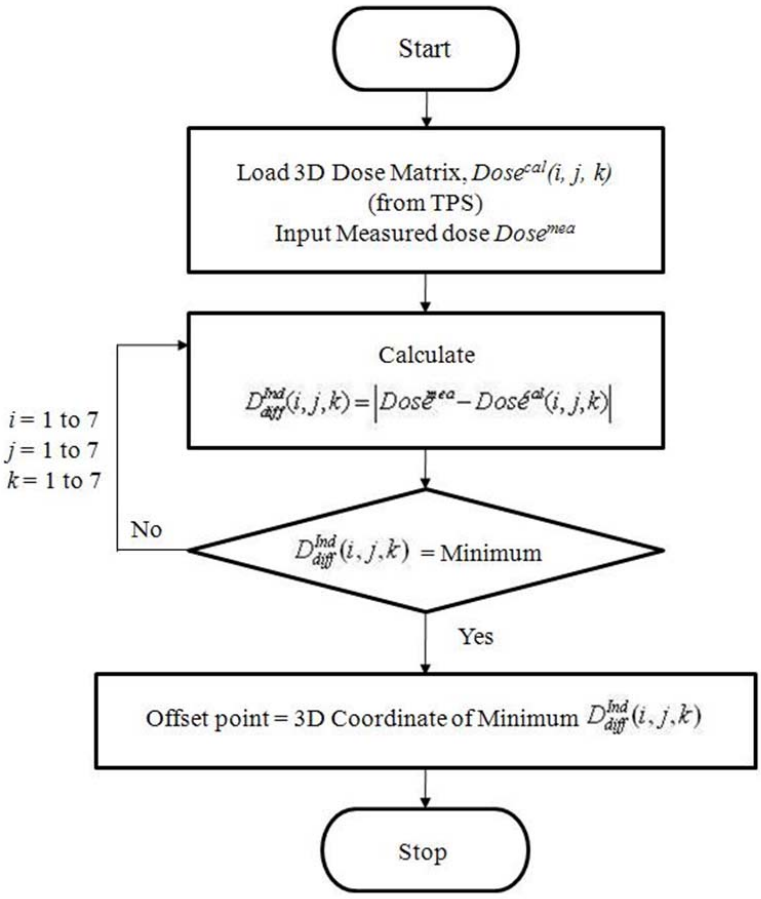

Fig. 1. Schematic to seek the offset point.

DQA measurements satisfied the above tolerance. However, some individual field dose differences were larger than ±10% even for the individual field that contributed more than 10 cGy to the total dose. Basran and Woo [2] reported that for head and neck cases, large individual field dose differences were observed even when fields with small dose contributions were excluded. Assuming that the selected dose point was in high dose gradients or close to multi-leaf collimator (MLC) leaf ends in one or a few of the segments, they performed new measurements by selecting new dose points. At the new dose points, 22 out of 39 plans passed their tolerance level of ±4%. Likewise, previous studies [15−19] showed that such large difference mainly stemmed from setup errors in conjunction with high dose gradients near a dose point.

However, none of the previous studies have yet demonstrated such correlation quantitatively in a systematic manner. In this study our DQA results for the last 2 years were divided into two groups: control vs. examination. By comparing the DQA results of both groups in terms of dose gradients, geometric offsets, and 3D offset distribution, we intended to present the quantitative data that supports the above conclusion.

2. MATERIALS AND METHODS

In our institution, patients were treated with dynamic IMRT using a Varian Clinac^{TM} 6EX or 21EX Linac equipped with a 120 Millennium^{TM} MLC (Varian Medical Systems, Palo Alto, CA). Point dose measurements were performed by using a 0.125 cc ion-chamber (semiflex, PTW, Freiburg, Germany) inserted into a cylindrical acryl phantom. A verification plan with the same fluence maps as the treatment plan was generated on CT images of the phantom in the TPS (Varian Medical Systems, Eclipse^{TM}) and delivered to the phantom at the planned gantry and collimator angles. The active volume of the ion-chamber was contoured as a region of interest (ROI) on CT images so that its dose distribution and dose volume histogram were calculated.

A point of measurement was selected in the region of high (more than 80% of the prescription dose) and uniform dose that dose difference between both points of ±3 mm centered the point of measurement along the x, y, and z axes was less than 2% of the prescription dose, which was usually within the planning target volume (PTV).

From July 2006 to July 2008, a total of 184 IMRT DQA measurements were performed according to the method described above. The DQA results showed a passing rate of 92.2% in a criteria of ±3% and 98.5% in a criteria of ±5%. Among them, a total of 16 DQA cases showed large individual field dose differences (> ±10%) for the fields with planned doses of > 10 cGy even though their total dose differences were less than or equal ±5%. The total number of such individual fields was 17 because one DQA case had two of such fields. These fields were defined as the examination group. Five DQA cases of which all individual fields showed less than ±5% dose difference were selected as the control group (a total of 30 individual fields). The total dose differences for both the control and the examination groups were all less than ±5%. The individual field dose difference (D_{diff}^{Ind}) and the total dose difference (D_{diff}^{Tot}) were calculated as follows:

$$D_{diff}^{Ind}(\%) = \frac{Dose^{mea} - Dose^{cal}}{Dose^{cal}} \times 100 \quad (1)$$

$D_{diff}^{Tot} = \sum_{i=1}^{N} D_{diff}^{Ind}(i)$, N = the total number of fields, (2)

where $Dose^{mea}$ and $Dose^{cal}$ were measured and calculated doses, respectively.

Table 1. Dose Gradient within 3 mm from the Verification Point along X, Y, and Z Axes.

	Dose Variation of Control Group (cGy/mm)			Dose Variation of Examination Group (cGy/mm)		
	Maximum Value	**Average Value**	**Standard Deviation**	**Maximum Value**	**Average Value**	**Standard Deviation**
x	0.26	0.21	0.04	1.18	0.64	0.31
y	0.32	0.20	0.08	1.20	0.48	0.36
z	0.21	0.15	0.06	0.79	0.28	0.19

x: Left to Right Lateral Direction

y: Anterior to Posterior Direction

z: Craniocaudal Direction

Table 2. Verification Point Offsets and Individual Field Dose Difference between Calculation and Measurement at Both Original Point and Offset Point.

Pt. No.	Field No.	Calculated Dose[a] (cGy)	Measured Dose (cGy)	Dose Difference[b] (%)	Verification Point offset (x, y, z)(cm)	Calculated Dose at offset Point(cGy)	Dose Difference at Offset Point[c] (%)	Dose Difference at Offset Point (cGy)
1	4	21.5	28.4	+32.1	(-0.2, +0.2, -0.2)	28.4	0	0.0
2	7	20.7	17.2	+16.9	(-0.2, +0.2, 0.0)	17.2	0	0.0
3	5	25.7	29.2	+13.6	(+0.2, 0.0, -0.1)	29.2	0	0.0
4	4	16.9	15.2	-10.1	(0.0, 0.0, +0.1)	15.2	0	0.0
5	1	17.6	19.7	+11.9	(+0.1, 0.0, +0.2)	19.7	0	0.0
6	6	41.3	29.5	-28.6	(+0.2, +0.1, 0.0)	29.5	0	0.0
7	6	21.8	24.8	+13.8	(-0.2, -0.2, -0.2)	24.8	0	0
8	7	26.2	22.4	-14.5	(0.0, -0.3, 0.0)	23.9	-6.3	1.5
9	6	23.9	20.6	-13.8	(+0.1, -0.2, -0.2)	20.6	0	0.0
10	5	21.5	18.9	-12.1	(0.0, -0.1, +0.1)	18.9	0	0.0
11	1	23.7	26.3	+11.0	(0.0, -0.2, 0.0)	26.3	0	0.0
	4	40.0	35.4	-11.5	(0.0, -0.2, 0.0)	35.4	0	0.0
12	3	22.3	19.6	-12.1	(+0.2, 0.0, 0.0)	19.6	0	0.0
13	7	34.2	28.8	-15.8	(+0.3, +0.3, 0.0)	31.0	-7.1	2.2
14	4	17.1	14.3	-16.4	(+0.3, 0.0, 0.0)	15.8	-9.5	1.5
15	3	28.3	25.1	-11.3	(-0.3, 0.0, 0.0)	26.3	-4.6	3.2
16	6	13.4	11.3	-15.7	(-0.3, +0.3, 0.0)	12.5	-9.6	1.6

[a]Calculated dose: Dose calculated in Eclipse™ treatment planning system at the original verification point

[b]Dose difference (%): (Measured dose − Calculated dose) / Calculated dose × 100

[c]Dose difference at offset point (%): (Measured dose − Calculated dose at offset point) / Calculated dose at offset point × 100

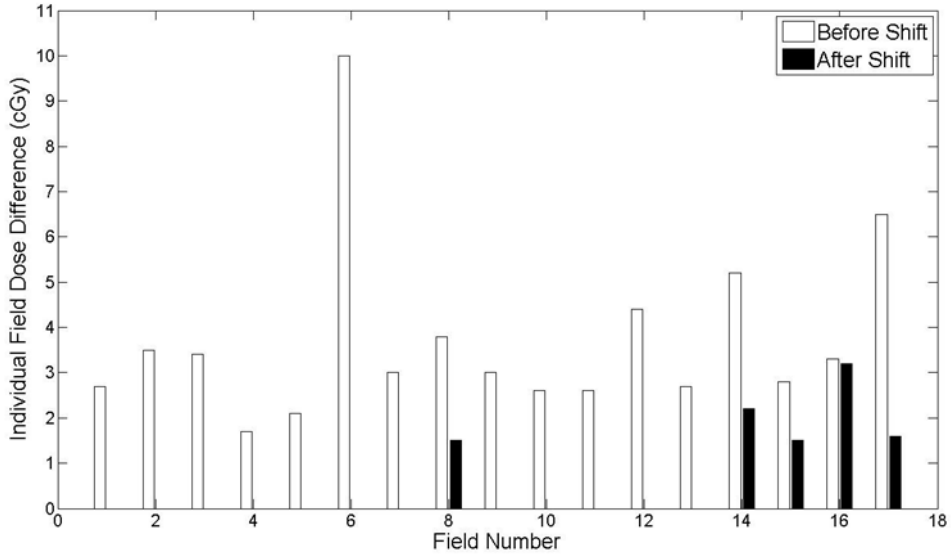

Fig. 2(a)

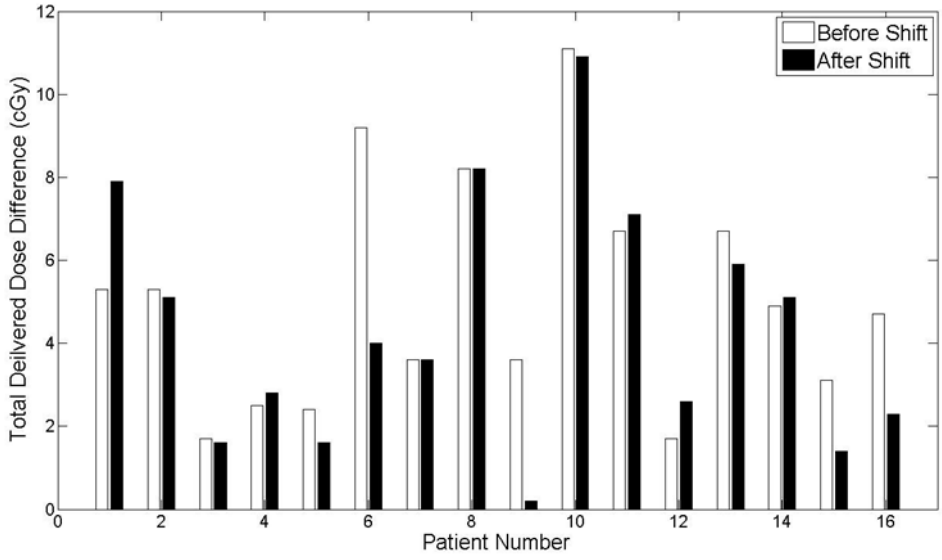

Fig. 2(b)

Fig. 2. Dose difference at offset point. Dose difference decreased in all individual fields with 12 fields being zero (a), Total dose difference decreased in most cases (b).

The DICOM dose files of both groups were exported from the TPS and converted into the ASCII dose files. Under the assumption that the DQA results of the examination group were perturbed by setup errors, we explored their 3D dose gradients within a cube of 6 × 6 × 6 mm^3 centered at a verification point (origin of the coordinate). The exploring range of ±3 mm along the x, y, and z axes was from the total setup error including random and possible setup errors due to the room laser misalignment [20]. Dose gradients of both groups were calculated to compare the DQA results of both groups in terms of dose gradients. The doses in a 0.1 mm-resolution inside the cube (total 343 points) were compared to seek a point (denoted as offset point) where the individual field dose difference was minimized. A custom-made program using Matlab™ (The Mathworks, Natick, MA, USA) was coded for this purpose. The flow chart of this program is shown in Fig. 1. At the offset point, the total and individual field dose differences were recalculated.

3. RESULTS

The average dose gradients of the control group in the cube along the x, y, and z axes were 0.21±0.04 cGy·mm^{-1}, 0.20±0.08 cGy·mm^{-1}, and 0.15±0.06 cGy·mm^{-1}, respectively (Table 1). The corresponding values of the examination group were 0.64±0.31 cGy·mm^{-1}, 0.48±0.36 cGy·mm^{-1}, and 0.28±0.19 cGy·mm^{-1}, respectively. The dose gradients of the examination group were about 2-3 times larger than those of the control group. This indicated that there was a strong correlation between the dose gradients and the DQA results (p-value: 0.05).

Figure 2(a) demonstrates that the individual field dose differences at the offset points were significantly reduced. Inside the cube (6 × 6 × 6 mm^3), it was possible to find an offset point where the calculated dose was almost the same as the measured dose (12 out of 17 fields) or in a better agreement with the measured dose (5 out of 17). Therefore, the mean of 17 individual field dose differences was reduced from 15.4% to 2.2% when considering the offset. The 11 out of 16 DAQ (note that one case had two individual fields having over 10% dose difference) results at the offset point showed a better agreement with measured total doses than the original results (Fig. 2(b)). Thus, the mean of total dose differences was also reduced from 3.1% to 2.2%. Table 2 summarizes offset points and individual field dose differences at the offset points for fields of the examination group. The individual field dose differences were up to ±10 cGy. However, the individual field dose differences at the offset points were all less than ±3.2 cGy. The distributions of offset points are shown in Fig. 3 [X-Y plane (a), X-Z plane (b), Y-Z plane (c)]. In five individual fields, the amount of offset reached to 3 mm (the maximum offset investigated) in at least one axis. The most of others showed 2 mm offset in at least one axis. The average amount of offset along the x, y, and z axes was 0.01±0.19 cm, -0.01±0.18 cm, and -0.02±0.10 cm, respectively. With the average amount of offset close to zero, it is considered that the amount of systematic error was minimal. The average amount of absolute offset (i.e., regardless of + or – direction) along the x, y, and z directions were 0.15±0.11 cm, 0.14±0.11 cm, and 0.06±0.08 cm, respectively. This indicated that setup errors along the x and y directions were larger than that along the z direction (longitudinal direction of the couch).

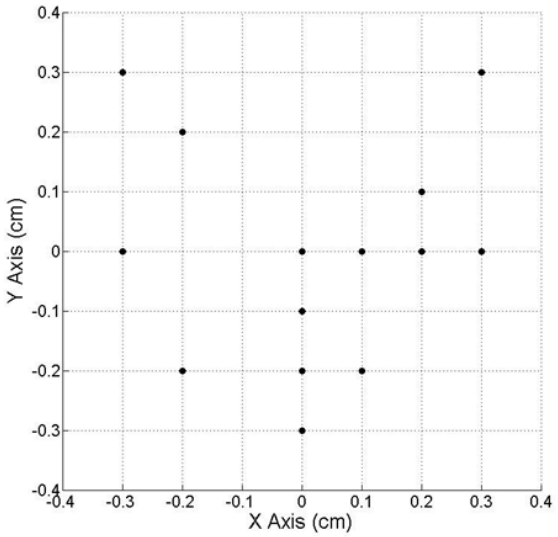

Fig. 3(a)

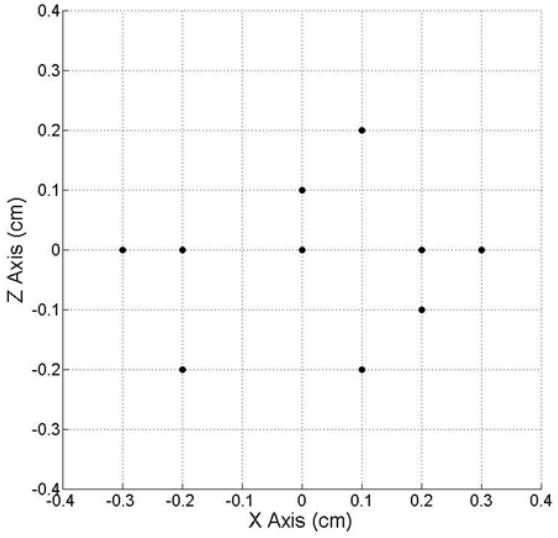

Fig. 3(b)

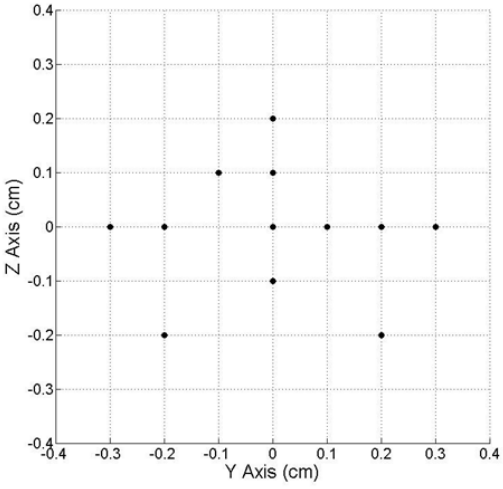

Fig. 3(c)

Fig. 3. X-Y (a), X-Z (b), and Y-Z (c) distributions of offset points, which represent the amount of offsetting with respect to the verification point.

4. DISCUSSION AND CONCLUSIONS

The sources of difference between measured and calculated doses fall into the following three categories: treatment planning system, delivery system, and measurement process [3, 13, 21−23]. The passing rates of 92.2% in the criteria of ±3% and 98.5% in the criteria of ±5% for our IMRT DQA results supported that the TPS and delivery systems were appropriately commissioned [13, 24]. Our local confidence limits of both point and 2D per-field measurements were 3.8% and 90% passing rate, respectively. We used a 2D-ARRAY seven29 with 729 ion chamber (OCTAVIUS Detector 729, PTW, Freiburg, Germany) and gamma criteria of 3%/3 mm for the 2D per-field measurement. Our local confidence limits were comparable to the corresponding values of AAPM TG 119 that were provided as a practical baseline (93% at 95% confidence level) for IMRT commissioning. The large individual field dose differences (> ±10%) were observed only in 16 DQA plans of the examination group (out of 184 DQA results). In addition, the offset points of the examination group were randomly distributed in the 3D coordinate. These indicated that there were no systematic errors in our TPS, delivery systems, and measurement procedure.

To the best of our knowledge, this study first provided the quantitative data that support the large individual field dose difference of IMRT DQA mainly stems from possible geometric errors (e.g., random setup errors) under the influence of steep dose gradients of IMRT field.

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REFERENCES

1. Ezzell GA, Galvin JM, Low D, et al. Guidance document on delivery, treatment planning, and clinical implementation of IMRT: report of the IMRT Subcommittee of the AAPM Radiation Therapy Committee. Med Phys. 2003 Mar;30(8):2089−2115.
2. Basran PS and Woo MK. An analysis of tolerance levels in IMRT quality assurance procedures. Med Phys. 2008 Apr;35(6):2300−2307.
3. Alber M, Broggi S, Wagter CD, Eichwurzel I, Engström P, Fiorino C, Georg D, Hartmann G, Knöös T, Leal A, Marijnissen H, Mijnheer B, Paiusco M, Sánchez-Doblado F, Schmidt R, Tomsej M, Welleweerd H: Guidelines for the verification of IMRT. Brussels, Belgium: ESTRO, 2008.
4. Woo MK and Nico A. Impact of multileaf collimator leaf positioning accuracy on intensity modulation radiation therapy quality assurance ion chamber measurements. Med Phys. 2005 May;32(5):1440−1445.
5. Breen SL, Moseley DJ, Zhang B, Sharpe MB. Statistical process control for IMRT dosimetric verification. Med Phys. 2008 Oct;35(10):4417−4425.
6. Dong L, Antolak J, Salehpour M, et al. Patient-specific point dose measurement for IMRT monitor unit verification. Int J Radiat Oncol Biol Phys. 2003 Feb;56(3):867−877.
7. Bouchard H and Seuntjens J. Ionization chamber-based reference dosimetry of intensity modulated radiation beams. Med Phys. 2004 Sep;31(9):2454−2465.
8. Tsai JS, Wazer DE, Ling MN, et al. Dosimetric verification of the dynamic intensity-modulated radiation therapy of 92 patients. Int J Radiat Oncol Biol Phys. 1998 Dec;40(5):1213−1230.
9. Stasi M, Baiotto B, Barboni G, Scielzo G. The behavior of several micro-ionization chambers in small intensity modulated radiotherapy fields. Med Phys. 2004 Oct;31(10):2792−2795.
10. Martens C, De Wagter C, De Neve W. The value of the PinPoint ion-chamber for characterization of small field segments used in intensity-modulated radiotherapy. Phys Med Biol. 2000;45:2519−2530.
11. Leybovich LB, Sethi A, Dogan N. Comparison of ionization chambers of various volumes for IMRT absolute dose verification. Med Phys. 2003 Feb;30(2):119−123.
12. Capote R, Sanchez-Doblado F, Leal A, Lagares JI, Arrans R, Hartmann GH. An EGSnrc Monte Carlo study of the microionization chamber for reference dosimetry of narrow irregular IMRT beamlets. Med Phys. 2004 Sep;31(9):2416−2422.
13. Ezzell GA, Burmeister JW, Dogan N, et al. IMRT commissioning: multiple institution planning and dosimetry comparisons, a report from AAPM Task Group 119. Med Phys. 2009 Nov;36(11):5359−5373.
14. Clark CH, Hansen VN, Chantler H, et al. Dosimetry audit for a multi-centre IMRT head and neck trial. Radiother Oncol. 2009;93:102−108.
15. Clark CH, Miles EA, Guerrero Urbano MT, et al. Pre-trial quality assurance processes for an intensity-modulated radiation therapy (IMRT) trial: PARSPORT, a UK multicentre Phase III trial comparing conventional radiotherapy and parotid-sparing IMRT for locally advanced head and neck cancer. Br J Radiol. 2009 Jul;82:585−594.

16. Pawlicki T, Yoo S, Court LE, et al. Moving from IMRT QA measurements toward independent computer calculations using control charts. Radiother Oncol. 2008;89:330–337.
17. Palta JR, Liu C, Li JG. Quality assurance of intensity-modulated radiation therapy. Int J Radiat Oncol Biol Phys. 2008;71:S108–112.
18. Losasso T. IMRT delivery performance with a Varian multileaf collimator. Int J Radiat Oncol Biol Phys. 2008;71:S85–88.
19. Hellman S, Ling CC, Leibel SA, et al. A practical guide to intensity-modulated radiation therapy. A practical guide to intensity-modulated radiation therapy. Madison (WI): Medical Physics Publishing; 2003:158–159.
20. Kim H, Park Y, Park J, et al. Assessment of Setup Errors and a New PTV Margin for Prostate Cancer Patients with an Endorectal Balloon. Int J Radiat Oncol Biol Phys. 2009;75:S637.
21. Ibbott GS, Followill DS, Molineu HA, Lowenstein JR, Alvarez PE, Roll JE. Challenges in credentialing institutions and participants in advanced technology multi-institutional clinical trials. Int J Radiat Oncol Biol Phys. 2008;71:S71–75.
22. Giorgia N, Antonella F, Eugenio V, Alessandro C, Filippo A, Luca C. What is an acceptably smoothed fluence? Dosimetric and delivery considerations for dynamic sliding window IMRT. Radiat Oncol. 2007 Nov;2:42–254.
23. Yan G, Liu C, Simon TA, Peng LC, Fox C, Li JG. On the sensitivity of patient-specific IMRT QA to MLC positioning errors. J Appl Clin Med Phys. 2009;10(1):120–128.
24. Breen SL, Moseley DJ, Zhang B, Sharpe MB. Statistical process control for IMRT dosimetric verification. Med Phys. 2008 Oct;35(10):4417–4425.