Original Article

PMP

Progress in Medical Physics 28(1), March 2017
https://doi.org/10.14316/pmp.2017.28.1.16
pISSN 2508-4445, eISSN 2508-4453

Evaluation of Dual-channel Compound Method for EBT3 Film Dosimetry

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Received 17 March 2017
Revised 27 March 2017
Accepted 27 March 2017

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This study assessed the feasibility of a dual-channel (DC) compound method for film dosimetry. The red channel (RC) is usually used to ensure dosimetric quality using a conventional fraction dose because the RC is more accurate at low doses within 3 Gy than is the green channel (GC). However, the RC is prone to rapid degradation of sensitivity at high doses, while degradation of the GC is slow. In this study, the DC compound method combining the RC and GC was explored as a means of providing accurate film dosimetry for high doses. The DC compound method was evaluated at various dose distributions using EBT3 film inserted in a solid-water phantom. Measurements with 10×20 cm^2 radiation field and 60° dynamic-wedge were done. Dose distributions acquired using the RC and GC were analyzed with root-mean-squares-error (RMSE) and gamma analyses. The DC compound method was used based on the RC after correcting the GC for high doses in the gamma analysis. The RC and GC produced comparatively more accurate RMSE values for low and high doses, respectively. Gamma passing rates with an acceptance criterion of 3%/3 mm revealed that the RC provided rapid reduction in the high dose region, while the GC displayed a gradual decrease. In the whole dose range, the DC compound method had the highest agreement (93%) compared with single channel method using either the RC (80%) or GC (85%). The findings indicate that the use of DC compound method is more appropriate in dosimetric quality assurance for radiotherapy using high doses.

Keywords: Gafchromic EBT3 film, Film dosimetry, Dual-channel compound, Gamma analysis

Introduction

Modern radiotherapy techniques like stereotactic body radiotherapy (SBRT) and stereotactic radiosurgery (SRS) use high fractional doses of radiation. This permits the very precise and accurate delivery of the radiation dose. The approach increases the importance for dosimetric quality assurance (QA) before the treatment of each patient.[1-3] Various methods to verify dose distributions calculated by treatment planning systems (TPS) have been described.[4] Radiochromic film is commonly used to provide treatment dose verification and measure two-dimensional (2-D) dose distribution in external beam radiotherapy with high spatial resolutions, weak energy dependence, wide dose range, and tissue equivalence.[5]

Gafchromic EBT3 film (International Specialty Products, ISP, Wayne, NJ, released in 2011) was introduced in late 2011 to eliminate measurement orientation effects as well as Newton rings formed during film scanning. It enhances the accuracy of maintaining a dosimetric performance,

similar to the EBT2 predecessor.[6] The details of dosimetry using EBT3 film and a flatbed color scanner have been described.[7,8] EBT3 dosimetry is generally analyzed by the single color channel method for radiotherapy with a fractional dose less than 3 Gy. However, treatment dose verification using high doses (6~13 Gy) is less clear.[9-12] It has been known for a long time that the green channel (GC) method offers good usability in higher doses, although the red channel (RC) has high sensitivity in the conventional dose range.[13] Use of the RC for doses below 8 Gy and the GC for higher doses is recommended by the manufacture.[14]

The GC has not been regarded as a productive approach to verify the treatment dose of SBRT and SRS, due to the low sensitivity of the channel at low dose regions, such as organ at risk (OAR) and other normal tissues. To verify target and OAR doses for high-dose treatment, a dual-channel (DC) compound method combining the RC and GC could have merit, and was the subject of the present study. We investigated the feasibility of the DC compound method in EBT3 film dosimetry for high doses by comparing the single channel method using the RC and GC.

Materials and Methods

1. Film calibration

Gafchromic EBT3 film was used. Prior to the film dosimetry, the daily output of linear accelerator (LINAC) was checked with a Famer-type ion chamber by applying the AAPM TG 51 protocol on the day of the calibration.[15] Film was arranged in a solid water phantom (30×30×11.5 cm^3), 1.5 cm deeper than the phantom surface with a 10 cm solid water layer placed below the film to produce backscattered radiation. The source to skin distance was 100.0 cm. A net-optical density (netOD) curve was obtained by irradiating film with 6-MV photon beam of a TrueBeam LINAC (Varian Medical Systems, Palo Alto, CA) at the 10×10 cm^2 field and 0° gantry. Doses ranging from 0 to 15 Gy were used to convert the film OD to dose from the same film batch. Films were scanned by an Expression 11000 XL flatbed scanner (Epson America Inc., Long Beach, CA, USA) after 24 hours with an image resolution of a 72 dots per inch. The scanned images were acquired in transmission mode and landscape orientation. The scanner was always warmed up at least 30 min before use and five preliminary scans without film on the scanner bed were performed to eliminate the impacts of scanner noise. The netOD curves ($netOD_{RC}$ and $netOD_{GC}$) for RC and GC were determined as previously described.[16] Each netOD curves were shown in Fig. 1.

2. Measurement and evaluation for film dosimetry

To measure various dose-ranges, the dose distribution was generated in an Eclipse treatment planning system (TPS, version 11.0.34; Varian Medical Systems) using a 6-MV photon beam of 10×20 cm^2 field with 60° dynamic-wedge. An analysis anisotropic algorithm (AAA, version 11.0.34) was used to calculate the dose distribution. The plan was normalized to deliver a dose of 575 cGy at a depth of 6 cm in the solid-water phantom (30×30×16 cm^3). The calculated dose (D_{Calc}) with a 0.25×0.25 cm^2 dose resolution was exported in the digital imaging and communications in medicine (DICOM) format. The film was measured under the same phantom setup and beam configuration for planning. The measured dose distribution was acquired by using both netOD curves. To evaluate the difference between D_{Calc} and dose distributions (D_{RC} and D_{GC}) using the $netOD_{RC}$ and the $netOD_{GC}$, the dose-profiles (cross-line and in-line) and gamma analysis were compared. As shown in Fig. 2, the cross-line profile was extracted at depth of the normalization point for central-axis of the film. The in-

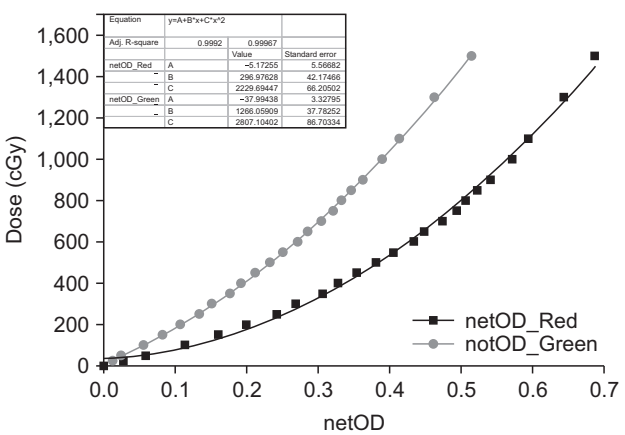

Fig. 1. Calibration net optical-density (netOD) curves for the red and green channel.

line profiles were obtained in five positions of –8, –4, 0, 4, and 9 cm (d1, d2, d3, d4, and d5, respectively) from the normalization point. The root-mean-square-error (RMSE) was used to analyze profiles of D_{RC} and D_{GC} compared to D_{Calc}. The gamma analysis described previously[17,18] was performed for dose distributions obtained by using both channels (RC and DC) and D_{Calc}.

3. Dual-channel compound method

The DC compound method was designed compounding the gamma value for D_{RC} and D_{GC}. It was based on the RC gamma analysis (GA_{RC}) after correcting the GC gamma analysis (GA_{GC}). The GA_{RC} was separated the failed-GA_{RC} ($\gamma>1$) and passed-GA_{RC} ($\gamma<1$). The failed-GARC was converted the GA_{GC} (convert-GA_{GC}) when the GA_{GC} passed at the same location. The DC gamma analysis (GA_{DC}) was defined ultimately as combination of the passed-GA_{RC} and the convert-GA_{GC}.

Results

1. Verification of cross- and in-line profiles

For the positions mentioned in Fig. 2, the cross-line and in-line profiles were acquired from D_{RC}, D_{GC}, and D_{Calc} of the measured film. Fig. 3 shows the comparison of cross-line and in-line profiles obtained in D_{RC}, D_{GC}, and D_{Calc}. The difference of cross-line profile for the D_{RC} and the D_{Calc} was increased remarkably in the high doses more than 8 Gy (Fig. 3a). Although the D_{GC} was also slight difference of cross-

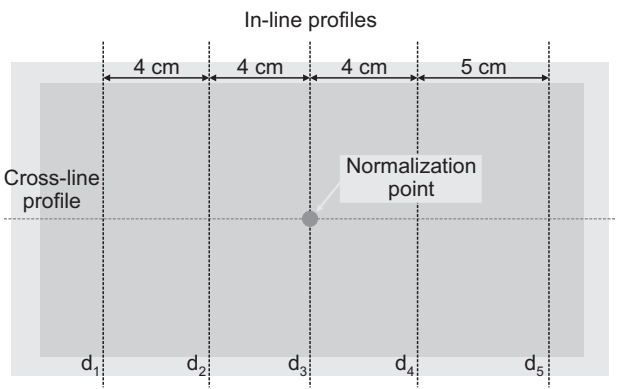

Fig. 2. EBT film showing a mimic image irradiated radiation for analyzing cross- (red dot line) and in-line (blue dot line) profiles.

Table 1. Root-mean-squares-error (RMSE) value for dose profiles in D_{RC}* and D_{GC}* compared to D_{Calc}*.

		RMSE between D_{RC} and D_{Calc}	RMSE between D_{GC} and D_{Calc}
Cross-line	Central axis	50.63	27.38
In-line	d1*	8.47	2.88
	d2*	6.31	8.38
	d3*	16.86	22.13
	d4*	21.15	31.44
	d5*	115.95	38.14

*d_1, d_2, d_3, d_4 and d_5: five positions of –8, –4, 0, 4, and 9 cm from the normalization point, respectively.
*D_{RC}, D_{GC}, and D_{Calc}: the dose distribution obtained by using red and green channel and calculated dose distribution.

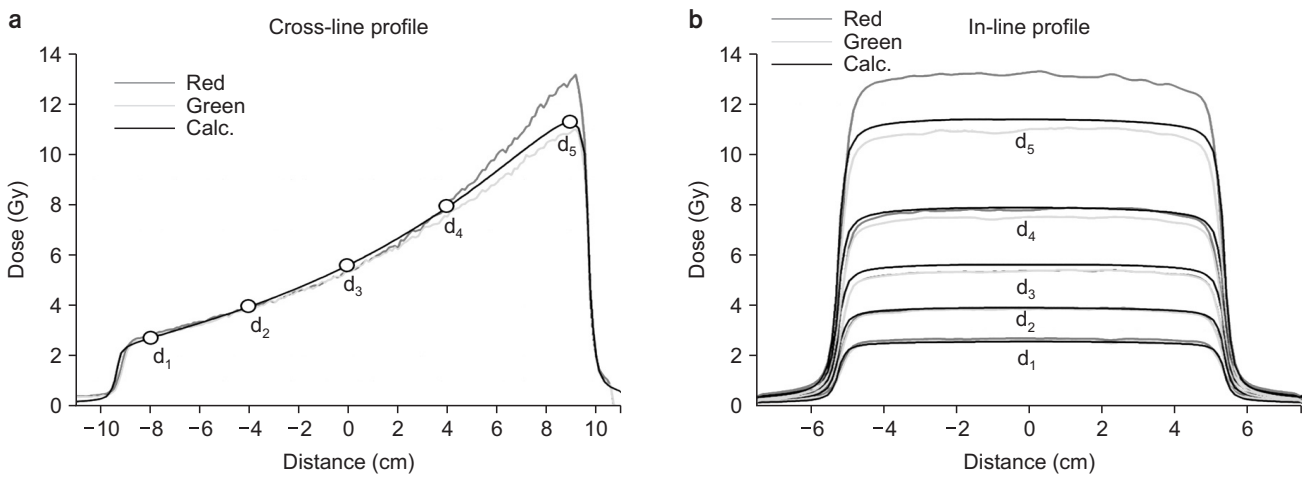

Fig. 3. The dose profiles ((a) cross-line and (b) in-line) obtained in D_{RC} and D_{GC} compared to D_{Calc}. The cross-line profile was measured in central-axis for dose distribution and the in-line profiles were measured in five positions of d_1, d_2, d_3, d_4, and d_5, respectively.

line profile with and the DCalc as dose increase, there is no significant difference. The in-line profiles of D_{RC}, D_{GC} and D_{Calc} were similar in four positions, excepted in d_5 of high dose region (Fig. 3b).

Table 1 shows RMSE values in profiles of D_{RC} and D_{GC} compared to D_{Calc}. The RMSE of the cross-line profile for D_{RC} was roughly twice as high as D_G. For the in-line profiles at positions d_1 to d_5, RMSE values of D_{RC} smoothly increased (within 21.15) to the d_4 position, with a steep increase to d_5. For the in-line profiles for the D_{GC}, the RMSE values were constantly increased (from 2.88 to 38.14) from d_1 to d_5. For in-line profiles of D_{RC} and D_{GC}, the difference in RMSE values was 5.59, –2.07, –0.98, –14.58, and 77.80 for d_1, d_2, d_3, d_4, and d_5, respectively.

Fig. 4 shows the distributions of GA_{RC}, GA_{GC}, GA_{DC} and convert-GA_{GC}. All distributions showed that the passing area decreased with increasing doses from 8 Gy. In the distribution of GA_{RC}, the gamma passing was the fastest decline in higher doses. Gamma values of convert-GA_{GC} were mainly distributed in the high dose region (Fig. 4d).

2. Gamma analysis in dose distribution for the red, green channel, and dual-channel method

Fig. 5 shows the gamma passing rates which was 3%/ 3 mm criteria in dose distributions using the RC, GC, and DC compound method. Most of passing rates for GA_{RC} were

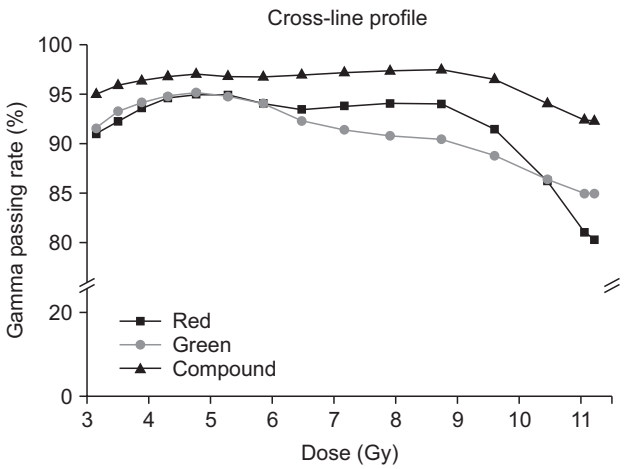

Fig. 5. Comparison of the gamma passing rates in dose distributions using the red channel, green channel, and dual-channel compound method with increasing doses.

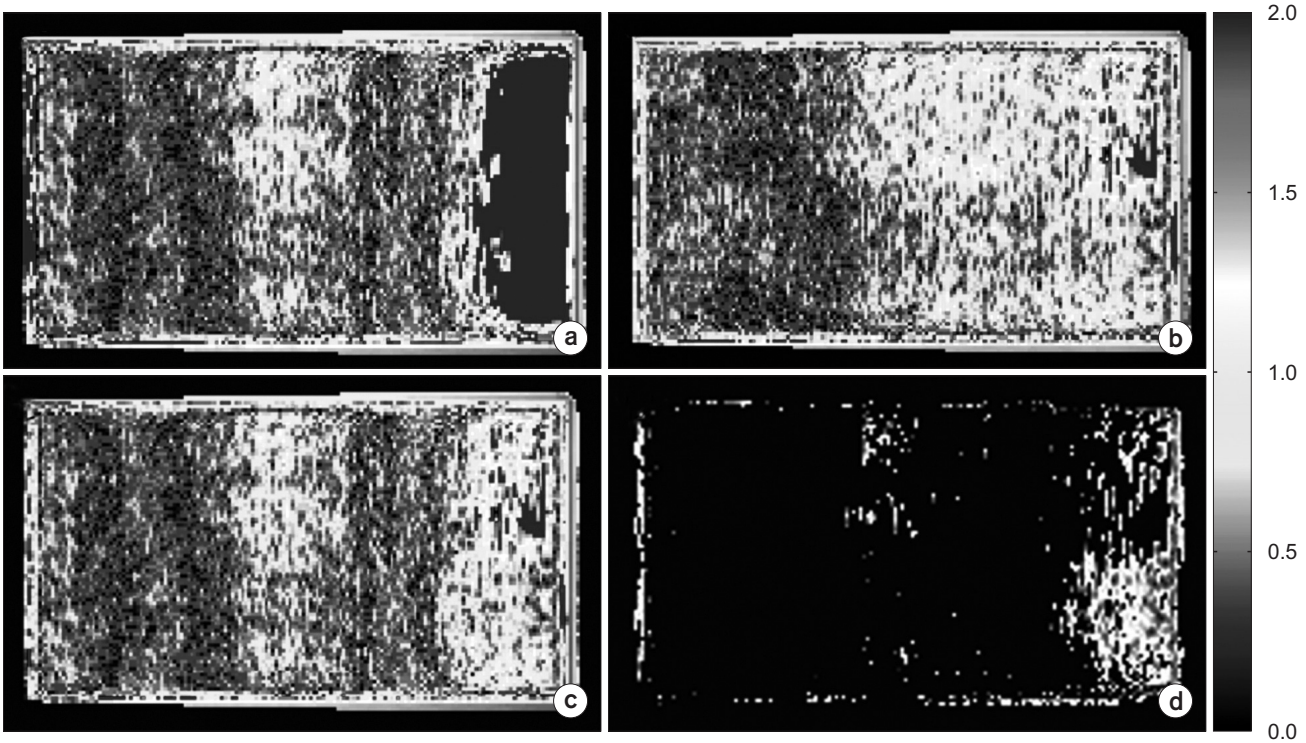

Fig. 4. Gamma distributions of analysis for (a) red, (b) green channel, (c) dual-channel compound method, and (d) the converted gamma distribution of green channel.

higher than those of GA_{GC} as dose level was up to 10 Gy. For high doses, the passing rates of GA_{RC} were lower than those of GA_{GC}. The gamma passing rates of GA_{DC} were the highest value among the gamma passing rates at overall dose regions, although the gamma passing rate of GA_{RC} and GA_{GC} was decreased. In 2%/2 mm criteria, the gamma passing rates of GA_{RC}, GA_{GC}, and GA_{DC} are 55.30%, 53.18% and 70.64%, respectively.

Discussion

In this study, the DC compound method for film dosimetry was evaluated in comparison to RC and GC. RC was more accurate within 8 Gy than the GC. RC was less accurate in high doses exceeding 8 Gy. The results echo those of prior studies.[13,14] The previous authors also mentioned that the GC for sensitometric curve exceeds the RC in high doses of more than 10 Gy. This was the basis of the DC compound method, which is based on the RC in low dose region after correcting for the GC in high dose region. Therefore, the gamma values in the convert-GA_{GC} were concentrated in the high dose region.

By using GA_{DC}, the gamma passing will increase in the low dose region because the failed-GA_{RC} was re-calculated using GA_{GC}. This means that the gamma passing of GA_{DC} in low doses needs to be double-checked using GA_{GC}. This double-check could decrease the film uncertainty using a single channel and increase the accuracy of the gamma analysis. Therefore, the use of the DC compound method may improve the accuracy for film dosimetry in the whole dose region.

As shown in Fig. 3, the difference between D_{GC} and the D_{Calc} was small in overall dose regions, while the difference between D_{RC} and the D_{Calc} was obviously in high doses. Borca et al.[13] reported that the film sensitivity for all color (RGB) channels decreased in high dose level. Our study found that the RC was good sensitivity within 8 Gy compared to RC. However, the RC exceeded sensitivity than GC when used in doses more than the 8 Gy. With depending on these channels trend, the differences between D_{Calc} and dose distributions (D_{RC} and D_{GC}) increased with dose increase, although the D_{GC} was more accurate than the D_{RC} in higher doses.

The DC compound method devised in this study will be more suitable in clinical radiation therapy, especially the dosimetric QA (DQA) for SBRT using high doses. In general, the result of DQA for SBRT is evaluated using the RC with the pretreatment QA plan downgraded for prescription dose. However, this downgraded evaluation has difficulty in reflect real clinical practice due to affect in variation of dose distribution and dose rate in pretreatment QA plan by dose degradation. Our DC compound method does not necessary need a dose downgrade for pretreatment QA plan. DQA is practical in the real clinical application. Therefore, we recommend the use of DC compound method in DQA using film dosimetry, especially in high dose treatments, such as SBRT and SRS.

The limitation of the DC compound method is that it was generated by gamma analysis. To perform a more accurate film dosimetry in whole dose region, it is necessary that each netOD curve is merged in a certain dose range. In future study, we will perform application of the merged netOD method for SBRT-DQA using film.

Conclusion

We evaluated the feasibility of DC compound method for the film dosimetry using EBT3. The method is a suitable film dosimetry for QA of treatment using high doses because it can be reduced errors in high dose verifications without the downgrade of prescription dose. Consequently, we recommend the use of DC compound method for film dosimetry of clinical SBRT-DQA.

Acknowledgements

This research was supported by a grant of the Korea Health Technology R&D Project through the Korea Health Industry Development Institute (KHIDI), funded by the Ministry of Health and Welfare, Republic of Korea (Grant Number: HI15C0638) and by a grant (2014R1A2A1A10050270) from the Mid-career Researcher Program through the National Research Foundation of Korea funded by the Ministry of Science, ICT & Future Planning.

Conflicts of Interest

The authors have nothing to disclose.

Availability of Data and Materials

All relevant data are within the paper and its supporting information files.

References

1. James MG, Greg B. Quality assurance procedures for stereotactic body radiation therapy. Int J Radiat Oncol Biol Phys. 2008;71:S122-5.
2. Eric EK, Joseph H, John B, Fang-Fang Y, William S, Sean D et al. TG Report 142: Quality assurance of medical accelerators. American Association of Physicists in Medicine. Med Phys. 2009;36:4197-212.
3. Huq MS, Fraass BA, Dunscombe PB, Gibbons JP, Ibbott GS, Medin PM, et al. A method for evaluating quality assurance needs in radiation therapy. Int J Radiat Oncol Biol Phys. 2008;71:S170-3.
4. Chung JB, Kang SW, Eom KY, Song C, Choi KS, Suh TS, Comparison of dosimetric performance among commercial quality assurance systems for verifying pretreatment plans of stereotactic body radiotherapy using flattening-filter-free beams. J Korean Med Sci. 2016;31:1742-8.
5. Hayashi N, Watanabe Y, Malmin R, Kato H. Evaluation of triple channel correction acquisition method for radiochromic film dosimetry. J Radiat Res. 2012;53:930-5.
6. Reinhardt S, Hillbrand M, Wilkens JJ, Assmann W. Comparison of gafchromic EBT2 and EBT3 films for clinical photon and proton beams. Med Phys. 2012;39:5257-62.
7. Devic S, Seuntjens J, Sham E, Podgorsak EB, Schmidtlein CR, Kirov AS, et al. Precise radiochromic film dosimetry using a flat-bed document scanner. Med Phys. 2005;32:2245-53.
8. Ferreira BC, Lopes MC, Capela M. Evaluation of an Epson flatbed scanner to read gafchromic EBT films for radiation dosimetry. Phys Med Biol. 2009;54:1073-85.
9. Fukumoto S, Shirato H, Shimzu S, Ogura S, Onimaru R, Kitamura K, et al. Small-volume image-guided radiotherapy using hypofractionated, coplanar, and noncoplanar multiple fields for patients with inoperable Stage I nonsmall cell lung carcinomas. Cancer. 2002;95:1546-53.
10. Gerszten PC, Burton SA, Welch WC, Brufsky AM, Lembersky BC, Ozhasoglu C, et al. Single-fraction radiosurgery for the treatment of spinal breast metastases. Cancer. 2005;104:2244-54.
11. Hara R, Itami J, Kondo T, Aruga T, Abe Y, Ito M, et al. Stereotactic single high dose irradiation of lung tumors under respiratory gating. Radiother Oncol. 2002;63:159-63.
12. Herfarth KK, Debus J, Lohr F, Bahner ML, Rhein B, Fritz P, et al. Stereotactic single-dose radiation therapy of liver tumors: results of a phase I/II trial. J Clin Oncol. 2001;19:164-70.
13. Borca VC, Pasquino M, Russo G, Grosso P, Cante D, Sciacero P, et al. Dosimetric characterization and use of GAFCHROMIC EBT3 film for IMRT dose verification. J Appl Clinic Med Phys. 2013;14:158-71.
14. Lewis D, Micke A, Yu X, Chan MF. An efficient protocol for radiochromic film dosimetry combining calibration and measurement in a single scan. Med Phys. 2012;39:6339-50.
15. Almond PR, Biggs PJ, Coursey BM, Hanson WF, Huq MS, Nath R, et al. AAPM's TG-51 protocol for clinical reference dosimetry of high-energy photon and electron beams. Med Phys. 1999;26:1847-70.
16. Devic S. Radiochromic film dosimetry: Past, present, and future. Phys Med. 2011;27:122-34.
17. Moran JM, Radawski J, Fraass BA. A dose-gradient analysis tool for IMRT QA. J Appl Clinic Med Phys. 2005;6:62-73.
18. Ju T, Simpson T, Deasy JO, Low DA. Geometric interpretation of the γ dose distribution comparison technique: Interpolation-free calculation. Med Phys. 2008;35:879-87.