Development of Preliminary Quality Assurance Software for GafChromic® EBT2 Film Dosimetry

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Software for GafChromic EBT2 film dosimetry was developed in this study. The software provides film calibration functions based on color channels, which are categorized depending on the colors red, green, blue, and gray. Evaluations of the correction effects for light scattering of a flat-bed scanner and thickness differences of the active layer are available. Dosimetric results from EBT2 films can be compared with those from the treatment planning system ECLIPSE or the two-dimensional ionization chamber array MatriXX. Dose verification using EBT2 films is implemented by carrying out the following procedures: file import, noise filtering, background correction and active layer correction, dose calculation, and evaluation. The relative and absolute background corrections are selectively applied. The calibration results and fitting equation for the sensitometric curve are exported to files. After two different types of dose matrixes are aligned through the interpolation of spatial pixel spacing, interactive translation, and rotation, profiles and isodose curves are compared. In addition, the gamma index and gamma histogram are analyzed according to the determined criteria of distance-to-agreement and dose difference. The performance evaluations were achieved by dose verification in the 60°-enhanced dynamic wedged field and intensity-modulated (IM) beams for prostate cancer. All pass ratios for the two types of tests showed more than 99% in the evaluation, and a gamma histogram with 3 mm and 3% criteria was used. The software was developed for use in routine periodic quality assurance and complex IM beam verification. It can also be used as a dedicated radiochromic film software tool for analyzing dose distribution.

Key Words: GafChromic EBT2, Quality assurance, Background correction, Active layer correction

INTRODUCTION

Film dosimetry is used in clinical sites to verify two-dimensional dose distribution and check the beam parameters for quality assurance (QA). GafChromic® EBT2 (International Specialty Products, Wayne, NJ) films have been reported to have potential for use in proximity to absolute doses without exhibiting the disadvantages of radiographic films.[1)] If the sensitometric curve can be obtained under accurate irradiation and film reading conditions using equipped tools,[2,3)] EBT2 films can become a recommended dosimeter for dose verification with easy handling.

Although an ionization chamber or a two-dimensional ionization chamber array can be effectively used for accurate dose measurement, it provides a low resolution for point dose measurements. Thus, EBT2 films are used for dose measurements because they possess characteristics such as high resolution, weak energy dependency, and ability to measure composite beams.[1-4)] The use of EBT2 films can be extended to QA by using them in intensity-modulated radiation therapy

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(IMRT) and in-vivo dosimetry for skin dose measurement.[4,5)]

Most established software for film dosimetry was configured for radiographic films based on gray channels. However, EBT2 films require a red channel-based sensitometric curve and appropriate background corrections to reduce the scattering effect originating from the flatbed scanner. To achieve a more accurate film dosimetry, the necessary functions can be supplemented by the developed software.

In this study, we developed QA software for the initial stage featuring calibrations based on each RGB channel and several approaches to background corrections for GafChromic® EBT2 film dosimetry. The functions of the software were tested by implementing application examples for dose comparison between the measured and calculated values obtained from EBT2 films and a treatment planning system (TPS).

MATERIALS AND METHODS

The software was developed using MATLAB (version R2008a, Mathworks, Natick, MA, USA) and is composed of two frames (Fig. 1), which display the imported and resultant images obtained at each processing step. Dose verification using EBT2 films are carried out in the following sequence on each tab panel: file import, noise filtering, background and active layer corrections, dose calculation, comparison, and evaluation. The measured doses from EBT2 films can be compared with the results from the TPS or two-dimensional ionization chamber array. The icons on the toolbar provide functions for image moving, zoom in, and zoom out. In addition, the data cursor can be used to read the pixel values (PVs) in any frames.

1. Corrections and calibrations

When films are imported, images corresponding to each color mode (red, green, blue, and gray) are automatically categorized and displayed (Fig. 1a). The required film images for dose verification can be selectively used. The calibration depending on each color channel can be implemented in the developed software.

For film calibration, an EBT2 film with dimensions of 8×10 in is cut into 25 rectangular pieces with dimensions of 5×4 cm. Different marks are left on each film piece to indicate the original position and film orientation. The film pieces are placed on the slab phantom (SP33, Scanditronix-Wellhofer,

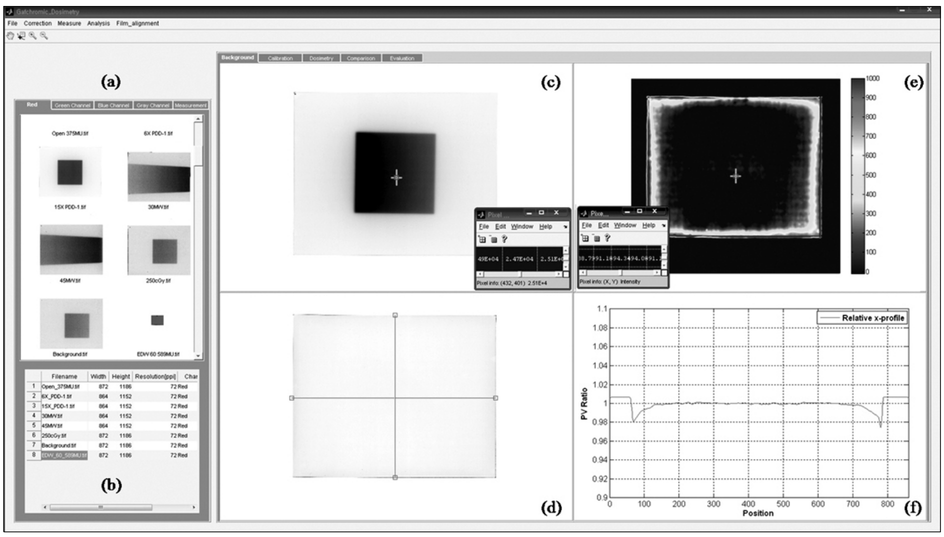

Fig. 1. Tab for background correction and analysis of scattering effect in developed software. (a) Frame displaying the imported images based on color channels: red, green, blue, and gray. (b) Table showing the image information and providing sub-items that can be used to select images for each process. (c) Selected EBT2 film for evaluating the measured dose. (d) Determination of the average pixel values in the central region of the unexposed film for relative background correction. (e) Matrix representing standard deviations from the average pixel values of the central region for absolute background correction. (f) Variation in the pixel values along the horizontal direction in landscape orientation.

Schwarzenbruck, Germany) for a source-to-surface distance of 100 cm with a field size of 10×10 cm. The films at the depth of maximum dose in the phantom are exposed to 6 MV photons. Doses of 10, 30, 50, 70, and 100 cGy are delivered in the low-dose range, while doses over 100 cGy up to 1,000 cGy are transferred at intervals of 50 cGy for film calibration.

The sensitometric curve and its fitting curve are plotted, and the calibration data and fitting results are then exported to the Excel (Fig. 2b) and text files, respectively. Whenever the saved calibration data are uploaded, dose calculation can be performed in the software. The fitting curves can be generated using the selection of listed functions, such as polynomial fits for different degrees or exponential functions (Fig. 2c). In addition, the relations between the dose and other factors, including optical densities (ODs), PVs, and deviations of ODs or PVs, are plotted in graphs according to the selections for the corresponding parameters of the x- and y-axes (Figs. 2d, f).

To reduce the scanner noise, the Wiener filter is applied to all imported images.[1] Relative or absolute background correction is selectively applied to compensate for intensity variation influenced by light scattering pixel-by-pixel. The relative background correction uses the matrixes representing the ratio of each PV to the average pixel value of the central region (avg. cPV) of the non-irradiated films. In contrast, the standard deviations (SDs) from the avg. cPV are used for the absolute background correction. These matrixes of the PV ratio and SDs are divided or subtracted to correct for the scattering effect using eqs. (1) and (2), respectively. The corrected PV matrixes $PV_{irradiate}^{Corr,relative}$ and $PV_{irradiate}^{Corr,\,absolute}$ can then be obtained from the original PV matrixes $PV_{irradiated}$ according to the applied method for background correction. k denotes the correction factor for the relative background correction, and the indexes i and j are the coordinates of the planar distribution.

$$PV_{irradiate}^{Corr,relative}(i,j)=\frac{PV_{irradiated}(i,j)}{k(i,j)} \quad (1)$$

$$PV_{irradiated}^{Corr,\,absolute}(i,j)=PV_{irradiated}(i,j)-SD(i,j) \quad (2)$$

The correction for the active layer thickness is appended to lessen the response differences between films in the same batch.[6] The red channel response is corrected by using the relation f(PV) between the red channel signals and red/blue values, as shown in eq. (3).

$$f(PV)^{corrected}=\frac{PV_{red}}{PV_{red}/PV_{blue}} \quad (3)$$

2. Analysis tool

After the dose measurements and calculations based on the EBT2 films are completed, the measured values are compared with the calculated values from TPS or other measured doses from different types of detectors. The developed software can read the output dose files exported from the two-dimensional ionization chamber array (I’mRT MatriXX, Scanditronix-

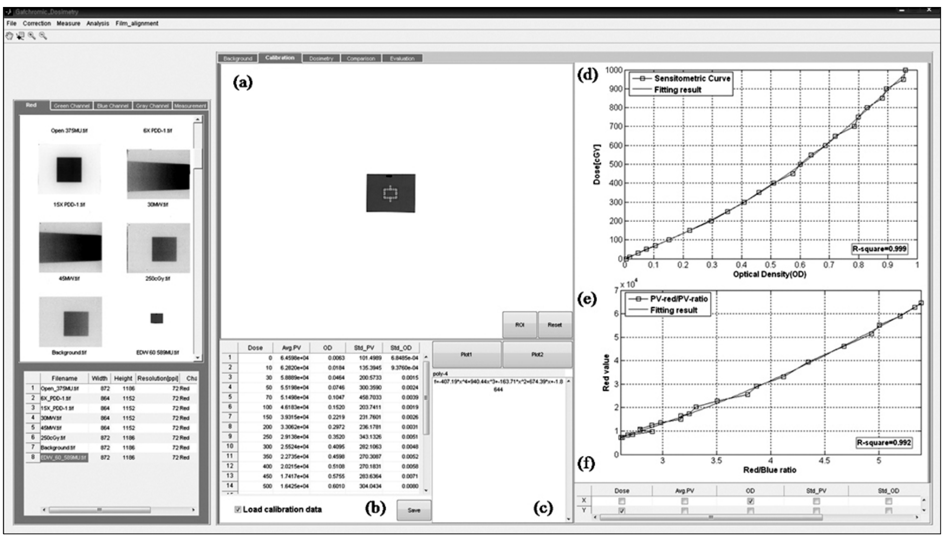

Fig. 2. Tab for film calibration and active layer correction in developed software. (a) Calculation of average pixel values in the calibration film. (b) Calibration data of the EBT2 film based on the red channel. (c) Fitting equation of the sensitometric curve. (d) Sensitometric curve and fitting result based on the fourth polynomial function. (e) Fitting curve for active layer correction. (f) Optional items to plot the relations between selected parameters for the x- and y-axes.

Wellhofer, Schwarzenbruck, Germany) and planning system (ECLIPSE version 6.5, Varian Medical Systems, Palo Alto, CA, USA). The beam data commissioning for the ECLIPSE system was performed by a 0.13-cc cylindrical ionization chamber (CC13, S/N-6003, Scanditronix - Wellhofer, IBA, Germany).

Any exported planar dose matrix determined by the three-dimensional coordinates from ECLIPSE can be imported and compared with those measured using the EBT2 film. The geometric alignment of the irradiated film can be set by adjusting the image translation and rotation. Moreover, the selected images with poor resolution (normally a 2.5 mm grid) from ECLIPSE can be interpolated to correlate with the finer resolution of the scanned film image. The selected dose distributions of the two different types are compared each other. As the geometric scale and coordinates are in agreement, qualitative and quantitative analyses can be achieved by using dose profiles, isodose curves, gamma index, and gamma histogram for the determined distance-to-agreement and dose difference levels.

3. Performance evaluation

To test the validity of the software, a 60^{o}-enhanced dynamic wedged (EDW) field and IM beams were applied for dose verification using the developed software. In the experiments, a SP33 phantom was scanned by computed tomography (CT), and the calculated dose distribution was then applied for a source-to-axis distance of 100 cm with a field size of 10×10 cm. The prescribed dose for 60^{o} EDW was 300 cGy, which was assumed to be an appropriate dose response based on the sensitometric curve for EBT2 films.

For generation of IM beams, the seven fields of the inverse plan for prostate cancer were used. A hybrid plan, which was configured by the composition for seven IM beams at the same gantry angles of the 0° position, was created to evaluate the performance of the developed software.

After being exposed for 1 day to allow for adequate post-exposed density growth, the irradiated films were scanned at the same reading conditions as those used for the acquisition of calibration data. All films were placed on the central flat panel of the scanner (Epson Expression 10000XL, Epson America Inc., Long Beach, CA, USA) in landscape orientation. To take the grid size in TPS into account for dose calculation, scanned film images were acquired for a resolution of 72 dpi (dots per inch), and a relative background correction was applied.

RESULTS

When the film images are imported, the loaded images are displayed on the left window, as shown in Fig. 1a. The file information (Fig. 1b) of the selected image can be checked using the tables, with the film image and file name matched together. Because imported images are loaded on multi-tabs for color channels, blue channel-based images are automatically prepared for active layer correction. In addition, the calibrations depending on each color mode can be applied to investigating the characteristics of GafChromic® EBT2 films.

For relative background correction, the avg. cPV in the region of interest (ROI) was determined on non-irradiated film, as shown in Fig. 1d. The scattering effect was analyzed; this differs according to the positions on the flat panel where the EBT films are placed. Both the horizontal and vertical variations of the PVs were less than 2% of the avg. cPV for the non-irradiated films, as shown in Fig. 1f. In the horizontal direction, PVs decreased almost symmetrically as they came closer to the end of the panel due to the lack of light reaching them. Using the sub-menus on the frame showing the profiles, the absolute and relative profiles in the vertical direction were also evaluated.

The scattering effect was also evaluated using SDs, as shown in Fig. 1e. The SDs of the effective regions on the scanning flatbed were less than approximately ±200, except for the approximately 2 cm margin from the boundary of the scanned EBT2 film. The scanner responses on the flat panel according to the spatial positions could easily be distinguished by color map. A SD matrix was applied for absolute background correction. Before post-operative processing, which includes filtering and background correction, each PV of the background and measured films can automatically show up through the added interactive windows, as shown in Fig. 1. Thus, the effect following the correction or filtering was evaluated based on the changes in PVs. After the correction matrix was completely configured and the measured film image was determined, as shown in Fig. 1c, the required filtering and corrections were applied to compensate for the variations in PVs influenced by noise and scattering effects.

As shown in Fig. 2a, average PVs in ROI and ODs were calculated in the films for calibration. The PVs, ODs, and their deviations were obtained in the table, as shown in Fig. 2b, whenever ROI was determined. If the OD and dose for the x- and y-axes are chosen as shown in Fig. 2f, the sensitometric curve can be plotted as shown by the black line marked square symbols in Fig. 2d. The blue line in Fig. 2d represents the fitting curve, and the fitting results were evaluated using the statistical R^2 values to show the goodness of curve fit. The fourth polynomial function fitted well to the sensitometric curve in comparison to the other fitting models. The fitting equation of eq. (4) was acquired as shown in Fig. 2c, and the equation was also verified in the saved text file “Calibration results.txt” in the working folder. The dose differences were estimated according to the degree of agreement between the fitting equation and sensitometric curve. As the doses were calculated using eq. (4) at the applied ODs of 0.569 and 0.785, which correspond to 450 and 700 cGy, the dose differences were approximately 2.1% and 3.9%, respectively, when compared to the delivered doses.

By applying the sensitometric curves based on the red and blue channels, the relation of eq. (3) was plotted as shown in Fig. 2e. Thus, eq. (5) was applied to correct the thickness differences of the active layer in the EBT2 film. After several corrections and noise filtering, the corrected PVs of the EBT2 films were converted to doses using eq. (4).

$$y(x) = -407.19x^4 + 940.44x^3 - 163.71x^2 + 674.39x - 1.8644 \quad (4)$$

$$y(x) = 2295x^2 + 2127x - 13808 \quad (5)$$

As shown in Fig. 3, the measured dose using the EBT2 film was compared with the dose using ECLIPSE in terms of the dose profiles for the x-axis, isodose curves, and gamma index. After geometrical alignment, the absolute dose profiles in the horizontal direction at the central y-axis were compared, as shown in Fig. 3a. The maximum value of the measured dose in a 60^o EDW field (429.4 cGy) was higher than that of TPS (421 cGy). At points where the dose discrepancy was higher than the surrounding points, the dose difference between 352.7 and 360.2 cGy of the EBT2 film and ECLIPSE, respectively, was lower than 3%. This result was also reflected in the analysis using the gamma index, which produced a distance-to-agreement of 3 mm and dose difference of 3%, as shown in Fig. 3b. Except for the edges showing the steep dose gradient, the regions within the irradiated field represented a gamma value lower than 1. The gamma histogram in Fig. 3d was also verified to have a 99% pass ratio. Isodose curves were compared, as shown in Fig. 3c; the small fluctuations are due to those in the EBT2 film.

The dosimetric results for IMRT QA, as shown in Fig. 4,

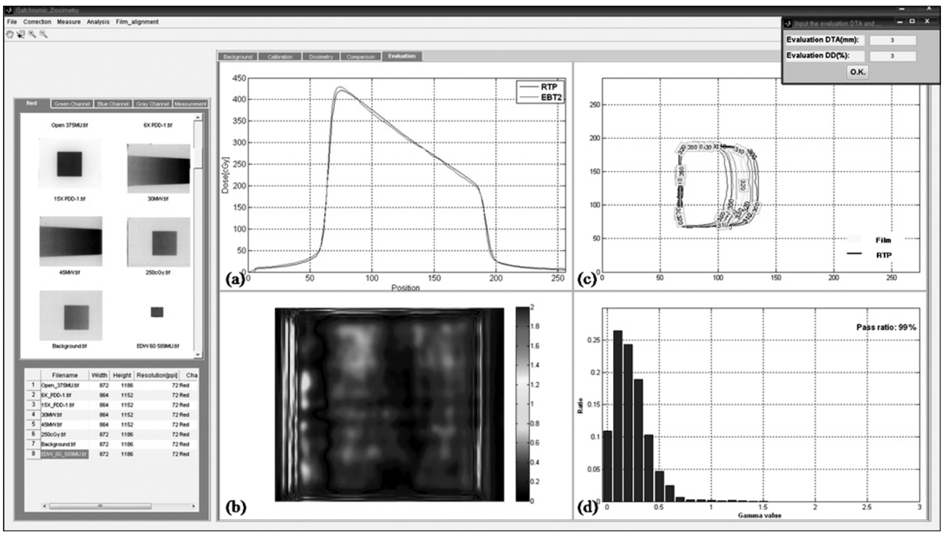

Fig. 3. Dose comparison between measured values using GafChromic® EBT2 films and ECLIPSE data in a 60^o-enhanced dynamic wedged field. (a) Absolute x-axis profile in the horizontal direction at the center of the field. (b) Gamma index distribution applied using a distance-to-agreement of 3 mm and a dose difference of 3%. (c) Comparison of isodose curves for dose levels with the box for EBT2 films and without the box for a planning system. (d) Analysis of gamma histogram according to the applied gamma criteria.

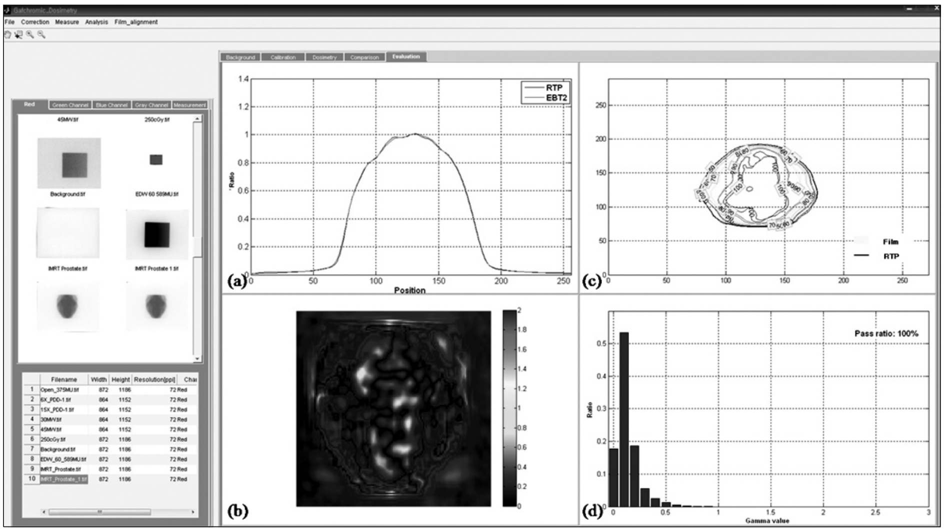

Fig. 4. Dosimetric quality assurance of prostate intensity-modulated radiation therapy (IMRT) using GafChromic EBT2 film and developed software. (a) Relative x-axis profile in the center of the irradiation field along the horizontal direction. (b) Gamma index distribution applied using a distance-to-agreement of 3 mm and a dose difference of 3%. (c) Comparison of isodose curves for dose levels with the box for EBT2 films and without the box for the planning system. (d) Analysis of gamma histogram according to the applied gamma criteria.

were also analyzed using the developed software. The relative dose profiles in Fig. 4a were compared with those from ECLIPSE along the horizontal direction. Moreover, the overall dose distributions were compared using isodose curves, as shown in Fig. 4c. Some portions corresponding to a 100% dose level showed differences in the shape and distance of the dose distribution, but rest of the isodose curves fell in line. As criteria of 3 mm and 3% for gamma evaluation were applied, the gamma index distribution and gamma histogram are represented in Figs. 4b and 4d, respectively. The gamma values of all voxels satisfied the criteria, and QA using the EBT2 film under IM beams was also possible using the developed software.

DISCUSSION AND CONCLUSION

Unlike radiographic films, GafChromic® EBT films require delicate post-image processing such as corrections for the scanner effect and intrinsic differences between films. Although many advantages of EBT2 films in radiation therapy have been reported, recommended correction methods and quantitative analysis results have not yet been thoroughly studied. Therefore, for in-depth evaluation and more accurate dose verification using GafChromic® EBT2 films, it is important to determine the optimal calibration conditions and correction methods considering individual scanner effects and the characteristics of EBT2 films.[1,7] Dosimetry using EBT2 films should also be tested for their feasibility and accuracy when used in QA.

Most existing commercial software is very easy to use and graphically improved, but they do not provide the required functions to correct the scattering effect on a flatbed scanner. They do not focus on red channel-based EBT film responses. Thus, the evaluation of EBT film dosimetry using existing software is difficult. In this study, customized and modifiable software was developed that can facilitate dose verification using EBT2 films. Moreover, the software provides proper functions for dose comparison between EBT2 films and other dosimeters.

The sensitometric curve tends to change depending on the scanning conditions and correction methods. Thus, agreement between the fitting equation and sensitometric curve is a factor that influences the accuracy of EBT2 film dosimetry.

Some recommended approaches for film dosimetry from vendors are controversial, such as the scanning mode and correction method. The analysis of various factors affecting the dose requires more investigation. Moreover, the appropriate correction methods can be reflected in the software procedures. The developed software should support QA using GafChromic® EBT2 films for more accurate and practical dose verification.

In conclusion, software for GafChromic® EBT2 film dosimetry was developed that enables analysis based on the color channel and corrections for the scattering effect and thickness differences in the active layer of films. In the performance tests using the 60° EDW field and intensity-modulated (IM) beams, good agreement was observed between the results of doses verification using the EBT2 film and ECLIPSE. The developed software is useful not only for routine periodic QA but also for IMRT QA. It can be applied to the analysis of planar dose distributions for radiochromic film dosimetry.

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GafChromic® EBT2 Film Dosimetry를 위한 품질 관리용 초기 프로그램 개발

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GafChromic EBT2 필름 dosimetry에 필요한 품질 관리용 소프트웨어를 개발하였다. 개발한 프로그램에서는 EBT2 필름 특성에 맞게 붉은색, 초록색, 파란색 및 회색 채널에 따른 필름 교정이 가능하도록 하였다. 또한 평판형 스캐너의 빛의 산란 효과나 필름 내 방사선에 반응하는 물질(active layer)의 두께 차이가 선량 검증에 미치는 영향을 평가할 수 있도록 하였다. EBT2 필름을 이용한 측정 결과는 방사선 치료계획 시스템, ECLIPSE 또는 2차원 이온 전리함 배열의 선량 값과 비교할 수 있다. 개발한 소프트웨어를 이용한 GafChromic EBT2 필름의 선량 검증은 파일 입력, 잡음 제거, 배경 보정(background) 및 반응 물질 보정(active layer correction), 선량 계산 및 평가 단계를 통해서 이루어진다. 절대적 또는 상대적 배경 보정 방법을 선택적으로 적용할 수 있으며 필름 교정 결과 및 교정 곡선에 대한 적합식(fitting equation)은 결과 파일로 출력할 수 있다. 선량 행렬의 화소 크기 조정을 위한 보간법, 대화식 영상 이동 및 회전 기능을 이용하여 선량 행렬 간 구조적 위치를 일치시킨 후, 빔 측면도(beam profile) 및 등선량곡선(isodose curve)을 비교할 수 있다. 또한 거리 및 선량 차이에 대한 허용값을 적용하여 gamma index 및 gamma histogram을 이용한 선량 분석이 가능하다. 60도 동적 쐐기 조사면과 전립선 세기조절방사선치료의 조사면을 이용하여 개발한 소프트웨어의 기초 성능 평가를 수행하였을 때, 동적 쐐기 조사면에서 ECLIPSE와 EBT2 필름 간 절대적 빔 측면도는 3% 오차 범위 내에서 일치하였다. EBT2 필름을 이용한 두 종류의 선량 검증 모두, 99% 이상의 영역이 3 mm, 3%의 gamma index의 평가 기준을 만족하였다. 개발한 선량 검증용 소프트웨어를 이용하여 주기적으로 수행되는 일반적인 품질관리뿐만 아니라 빔의 세기가 조절된 복잡한 조사면의 품질관리에도 활용할 수 있으며, Radiochromic 필름을 이용한 선량 평가에 필요한 유용한 분석 툴을 제공할 수 있다.

중심단어: GafChromic EBT2, 품질관리, 배경 보정, 반응 물질 두께 보정