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Characteristics of Gafchromic™ EBT film for dosimetric verification for high energy photon beams

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Objective : *The objectives of this research are to study the characteristics of Gafchromic™ EBT film for 6 MV x-ray beams and to verify isodose distribution of advanced radiation treatment techniques.*

Study design : *Observational descriptive study.*

Setting : *Division of Therapeutic Radiology and Oncology, Department of Radiology, Faculty of Medicine, Chulalongkorn University.*

Materials and Methods : *The characteristics of Epson perfection V700 flat-bed color CCD were observed for the response, the repeatability, the reproducibility and color band. The characteristics of Gafchromic™ EBT film were studied for speed of film development, polarization, uniformity, field size and dose rate effects. The percentage depth dose and beam profile were measured and compared with the data from 0.13 CC ionization chamber. The comparisons of fluence map in intensity modulated radiotherapy (IMRT) plans measured by film and calculated by Eclipse treatment planning were observed in two nasopharynx cancers and one brain tumor.*

Results : *Responses of Epson perfection V700 flat-bed color CCD in term of pixel value and net optical density showed polynomial curve. The variations of scanner reproducibility and repeatability were*

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within 1.0 and 1.1%, respectively. The Gafchromic™ EBT film was best evaluated in the red channel of the Epson perfection V700 scanner. The optical density growths with time seem to stabilize after 4 hours. The effect of EBT film polarization at 90^{O} and 270^{O}, with 50 cGy delivered dose was up to 24% difference of optical density when compared with orientation at 0^{O}. The variation of EBT film uniformity was 7 % at 400 cGy. Slightly deviation from the ionization chamber measurement for output factor for small field size and no dose rate dependence were observed for the range of dose rate study. The difference of percentage depth doses at 5 cm depth between EBT film and CC13 ionization chamber were less for all field sizes study. The deviation of beam profile between EBT film and CC13 ionization chamber was presented at the region of off-axis and high dose gradient. The fluence map of IMRT plans measured by Gafchromic™ EBT and calculated by Eclipse planning system of two nasopharynx cancers and one brain tumor were compared with the criteria of 3% dose difference and 3 mm distance to agreement. The two plans showed over 90% passed but one plan was below 90%.

Conclusion : *The characteristics of scanner should be observed before examining the characteristics of Gafchromic™ EBT film. The characteristics of film such as the speed of film development, polarization effect and uniformity are very important because of the stability time of net optical density and the direction of non-polarization effect should be selected. The uniformity of film is affected to dose distribution verification, it should be corrected before scanning the film. Then, the Gafchromic™ EBT films can be used to verify isodose distribution of advanced radiation treatment techniques.*

Keywords : *Gafchromic™ EBT film, Radiochromic film, Intensity modulation radiotherapy (IMRT), Dosimetric verification.*

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ปรเมศวร์ วงศ์จอม, ศิวลี สุริยาปี, ทวีป แสงแห่งธรรม, สรจรส อุณห์ศิริ, พันทิวา อินแสง. การศึกษาคุณสมบัติของฟิล์มชนิด Gafchromic™ EBT เพื่อใช้ในการตรวจสอบปริมาณรังสีของลำโฟตอนพลังงานสูง. จุฬาลงกรณ์เวชสาร 2554 พ.ค. – มิ.ย.; 55(3): 207 – 19

วัตถุประสงค์ : *การศึกษานี้มีวัตถุประสงค์เพื่อศึกษาคุณสมบัติของฟิล์มชนิด Gafchromic รุ่น EBT สำหรับลำโฟตอนพลังงานสูงและเพื่อที่จะตรวจสอบการกระจายปริมาณรังสีของลำโฟตอนพลังงานสูง ด้วยเทคนิคการรักษาที่ซับซ้อน*

การออกแบบการศึกษา : *การศึกษาโดยวิธีการสังเกตเชิงพรรณนา*

สถานที่ : *สาขารังสีรักษาและมะเร็งวิทยา ภาควิชารังสีวิทยา คณะแพทยศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย*

วัสดุและวิธีการ : *ทำการศึกษาหาคุณลักษณะของเครื่อง Scanner ยี่ห้อ Epson perfection V700 และ ฟิล์มชนิด Gafchromic รุ่น EBT การศึกษาคุณลักษณะของเครื่อง Scanner ประกอบด้วย การตอบสนองของเครื่อง Scanner ความสามารถในการทำซ้ำ ความสามารถในการทำใหม่ และ การตอบสนองของช่องสัญญาณแสงสี สำหรับการศึกษาคุณลักษณะของฟิล์มประกอบด้วย เวลาของค่าความเข้มสีคงที่ Polarization effect ความสม่ำเสมอของค่าความเข้มสี ผลของขนาดของลำรังสี และ ผลของอัตราปริมาณรังสี การวัดค่า Percentage depth dose และ Beam profile เพื่อเปรียบเทียบกับผลที่ได้จากการวัดโดย Ionization chamber ขนาด 0.13 ลบ.ซม. การเปรียบเทียบการกระจายของปริมาณรังสีโดยใช้ Fluence map ที่วัดได้จากฟิล์มกับการคำนวณการกระจายปริมาณรังสีด้วยเครื่องคอมพิวเตอร์ (Eclipse treatment planning) ด้วยแผนการรักษา 3 แผน คือ Nasopharynx cancer 2 แผนการรักษา และ Brain tumor 1 แผนการรักษา*

ผลการศึกษา : *การศึกษาคุณลักษณะของเครื่อง Scanner พบว่าการตอบสนองของเครื่อง Scanner โดยความสัมพันธ์ระหว่าง ค่าพิกเซล และ ค่าความเข้มสีมีลักษณะเป็นเส้นโค้งแบบ Polynomial ค่าความแปรปรวนของความสามารถในการทำใหม่และการทำซ้ำ อยู่ภายใน 1.0% และ 1.1% ตามลำดับ ช่องสัญญาณแสงสีแดงให้ค่าการตอบสนองสูงที่สุด การศึกษาคุณลักษณะของฟิล์ม พบว่าเวลาของค่าความเข้มสีคงที่ ประมาณ 4 ชั่วโมงหลังจากการฉายรังสี ผลกระทบของ Polarization จะเกิดมาก*

ที่สุดที่ 90^{O} และ 270^{O} เมื่อเปรียบเทียบกับมุม 0^{O} องศา และปริมาณรังสีมากจะมีผลกระทบน้อยกว่าปริมาณรังสีน้อย โดยปริมาณรังสี 50 cGy มีผลกระทบเพิ่มขึ้นถึง 24% ความแปรปรวนของค่าความสม่ำเสมอของความเข้มสี ของฟิล์มมีค่ามากถึง 7% สำหรับการฉายรังสีด้วยปริมาณ 400 cGy การวัดรังสีด้วยฟิล์ม พบว่ามีความแตกต่างจากการวัดด้วย Ionization chamber เล็กน้อยที่ขนาดลำรังสีแคบ ไม่ขึ้นกับอัตราปริมาณรังสีในช่วงของอัตราปริมาณรังสีที่ศึกษา ความแตกต่างกันของการวัด Percentage depth dose ระหว่างฟิล์มกับ Ionization chamber (CC13) พบว่ามีค่าความแตกต่างกันน้อย ค่าการเบี่ยงเบนของ Beam profile ระหว่างฟิล์ม กับ Ionization chamber (CC13) พบว่าเกิดขึ้นที่บริเวณ Off-axis และบริเวณที่มีการเปลี่ยนแปลงปริมาณรังสีสูง สำหรับการเปรียบเทียบการกระจายของปริมาณรังสีโดยใช้ Fluence map และใช้เกณฑ์ของค่าความแตกต่างของปริมาณรังสี 3% และ ความแตกต่างของระยะทาง 3 มม. พบว่า 2 แผนการรักษา แสดงค่าเปอร์เซ็นต์ผ่านเกิน 90% แต่อีก 1 แผนการรักษาแสดงค่าเปอร์เซ็นต์ผ่านน้อยกว่า 90%

สรุป : *การศึกษาคุณลักษณะของเครื่อง Scanner จำเป็นที่จะปฏิบัติเป็นอันดับแรกก่อนที่จะทำการศึกษาคุณลักษณะของฟิล์ม รุ่น EBT ซึ่งประกอบด้วยเวลาของค่าความเข้มสีคงที่ Polarization effect และความสม่ำเสมอความเข้มสีของฟิล์ม เนื่องจากควรเลือกช่วงเวลาที่เหมาะสมที่สุดในการนำฟิล์มมาอ่านค่าความเข้มสี และทิศทางของการ Scan โดยหลีกเลี่ยงผลกระทบของค่า Polarization ให้น้อยที่สุด สำหรับค่าความสม่ำเสมอความเข้มสีของฟิล์ม รุ่น EBTและเครื่อง Scanner รุ่น Epson perfection V700 จำเป็นต้องทำการแก้ค่าความแปรปรวนของสัญญาณก่อน เนื่องจากจะส่งผลกระทบมากต่อการตรวจสอบการกระจายของปริมาณรังสีที่วัดได้ จากการศึกษาคุณลักษณะของฟิล์มชนิด Gafchromic รุ่น EBT พบว่าสามารถใช้เป็นเครื่องมือใหม่ สำหรับลำโฟตอนพลังงานสูงเพื่อที่จะตรวจสอบการกระจายปริมาณรังสีด้วยเทคนิคที่ซับซ้อนได้*

คำสำคัญ : *ฟิล์ม Gafchromic^{TM} EBT, ฟิล์ม Radiochromic, Intensity modulation radiotherapy (IMRT), การตรวจสอบปริมาณรังสี.*

Nowadays, technologies of radiation treatment techniques have been developed to treat patient efficiency. The advanced techniques such as Intensity Modulated Radiotherapy (IMRT) require steep dose gradient by varying intensity of a number of small beam, the result is the conformal dose distribution to the irregular tumor and lower dose to healthy normal tissue.(1) The complexity of beam delivery makes it necessary to verify the consistency of the delivered dose and the calculated dose from treatment planning system.(2)

The delivered dose distributions from IMRT are difficult to verify with ion chamber because of the sharp dose gradient. The Gafchromic™ EBT film (International Specialty Products, Wayne, NJ, USA.) is introduced to verify the 2D dose distribution in this advanced technique. The Gafchromic™ EBT film is very attractive due to self development, high spatial resolution, and insensitive to visible light, minor energy dependence, and near tissue-equivalence.(3)

The implementation of radiochromic film for dose verification in IMRT need special attention of film and the scanner for the readout of film, i.e the Gafchromic™ EBT films need to be calibrated in dose response and corrected for pixel value and spatial dependent non-uniformity caused by light scattering. Menegotti et al.(4) demonstrated a method for a fast and accurate calibration and uniformity correction for radiochromic film with flat-bed scanner. Schmidtlein et al.(5) presented a measurement protocol to improve the precision of dose measurement using a flat-bed scanner with Gafchromic™ HS and prototype A EBT film. Ziedan et al.(6) presented Gafchromic™ EBT film for IMRTdose verification using flat-bed color CCD scanner, the dose response showed the agreement of Gafchromic™ EBT film to ion chamber scan in water for the depth dose and dose profiles. The effect of Gafchromic™ EBT film polarization with delivered dose and film scan orientation was shown to have a significant effect on the scanner optical density read out. Sankar et al.(1) compared Gafchromic™ EBT film with Kodak extended dose rang 2 (EDR2) film. There was a variation up to 8.5% in the film uniformity over its sensitive region. The EDR2 film showed consistent result with the calculated doses, where as the result obtained using EBT were comparable with the result of EDR2 only when the IMRT of small field were used.

This study aims to investigate the characteristics of Gafchromic™ EBT film and the Epson flat-bed scanner for dosimetric verification of 6 MV photon beams and to verify isodose distribution of IMRT treatment techniques.

Materials and Methods

The 6 MV x-ray beam from Clinac 21EX (Varian Medical System, Palo Alto, CF, USA.) was used in this study. The 20 x 25 cm^2 Gafchromic™ EBT film was employed. The Image J and MapCHECK version 3.05.02 software (Sun Nuclear Corp., Melbourne, Fl, USA.) were the tool for evaluation. The Epson Perfection V700 flat-bed scanner was warming up by continuous scanning at least five times without a film before scanning the Gafchromic™ EBT film.

A. Characteristics of flat-bed color scanner

The scanner employed a fluorescent light source with a broadband emission spectrum. The film with standard step wedge pattern of varying optical density was scanned by using 75 dpi spatial resolution and 48 bit-depth for scanner. The measured pixel values and net optical density of each step of standard step wedge film pattern were plotted to observe the response relationship. The standard step wedge film pattern was scanned with one band of 1.55 optical density for five days, ten times continuously each day for reproducibility and repeatability verification. Then, the graph for each day was plotted between the net optical density (reading measurement – reading background) and the scan number. The net optical density responses of scanner from red, green and blue color channels were observed for the irradiation of 10 to 700 cGy.

B. Characteristics of Gafchromic™ EBT films

The films were cut into 3 x 3 cm^2 size for characteristic study that consisted of speed of film development, field sizes, dose rate effects and finally sensitometric curve was plotted. The Gafchromic™ EBT films were placed horizontally inside virtual water phantom at 1.5 cm depth with 20 cm back scatter material. The films were irradiated to dose of 10 - 700 cGy with 6 MV photon beam. The films of 20 x 25 cm^2 at 5 cm in virtual water phantom were irradiated with 50 - 400 cGy for film uniformity and polarization effect. The irradiated films were analyzed by MapCHECK and Image J software.

C. Percentage depth dose and beam profile

The Gafchromic™ EBT films of 20 x 25 cm^2 size were placed parallel to the beam axis inside virtual water phantom at 100 cm source skin distance. The edges of films were aligned at the edge of phantom. The films were exposed for field sizes of 2 x 2 cm^2, 6 x 6 cm^2 and 10 x 10 cm^2, respectively. As for the percentage depth dose, the films were scanned vertically at the central axis from 0 to 15 cm depth while the films were scanned cross-line axis at 5 cm depth to obtain the beam profiles. The films were analyzed by MapCHECK software. The data were compared to the percentage depth dose and beam profile measured by CC13 Ionization chamber in water phantom.

D. Dose verification analysis

Three IMRT complex plans of two nasopharynx cancers and one brain tumor for 6 MV photon beams calculated by Eclipse treatment planning system version 7.3.10 (Varian Medical System, Palo Alto,CF, USA.) were verified with the measurement by the Gafchromic™ EBT films. The films were placed horizontally at 5 cm depth inside the virtual water phantom of 100 cm source axis distance. The Gafchromic™ EBT films were irradiated for composite field with gantry, collimator and couch of 0^{O} degree. The irradiated films were scanned 24 hours after the exposure. The dose calculations were loaded into the software for comparison. Then, the responses of EBT films and dose calculations were analyzed with MapCHECK software. The percent passed of IMRT was analyzed by Gamma index(7) which accepted at 3% dose difference and 3 mm distance to agreement.

Results

A. Characteristics of flat-bed color scanner

The relation between net optical density and pixel value of standard step wedge film pattern in Fig.1 shows the polynomial response. The variation for ten times repeated reading was within 1.1% and for five days reproducibility was within 1.0%. The response showed the trend of lower value for the higher scan number. The red channel of scanner demonstrated highly sensitive response than green and blue channels, so the red channel was selected in this study.

B. Characteristics of Gafchromic™ EBT films

1. Stability of film development

The stability of Gafchromic™ EBT film development in Fig.2 was about 4 hours after irradiation. The net optical densities ratio at different time (t) and time t_0 of 50, 100, 200 and 400 cGy were increased up to 7.1%, 6.4%, 6.2% and 4.9%, respectively, during 0 to 9 hours after irradiation.

2. Polarization effect

The response due to film orientation is shown in Fig.3. The polarization effect of Gafchromic™ EBT film was demonstrated at 90^O, 270^O degree film orientations. There was no effect at 0^O, 180^O and 180^O-flip orientation. The low response of Gafchromic™ EBT film polarizations depended on the amount of doses; low doses were more effective than higher doses. The effect of polarization made the variation due to dose dependence of about 5% for 400 cGy and 24% for 50 cGy.

3. Uniformity

The non-uniformity of pixel value gave the difference between the response at the edge and the center of the film about 7%, at 400 cGy for 18 x18 cm^2 region of interest (ROI) which is shown in Fig. 4. This effect was due to the non-uniformity of both Gafchromic™ EBT film and Epson Perfection V700 scanner. The smaller dose presented less non-uniformity effect than higher dose.

4. Field sizes effect

Variation of output factors compared with ionization chamber measurement for 2 x 2 cm^2 to 25 x 25 cm^2 field size is shown in Fig.5. The maximum of percentage difference between Gafchromic™ EBT film and CC13 ionization measurements was 2.01%, it occurred at small field size and was comparable for field size larger than 10 x 10 cm^2.

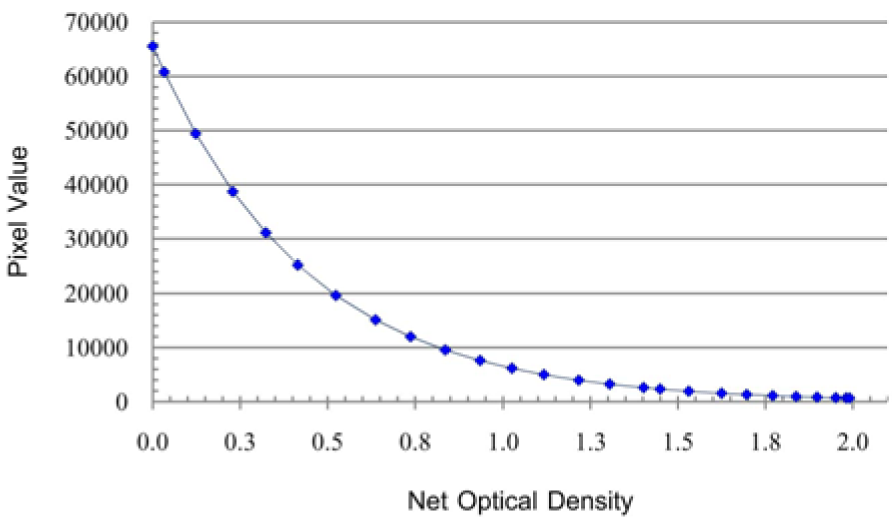


Figure 1. Responses of Epson Perfection V700 scanner.

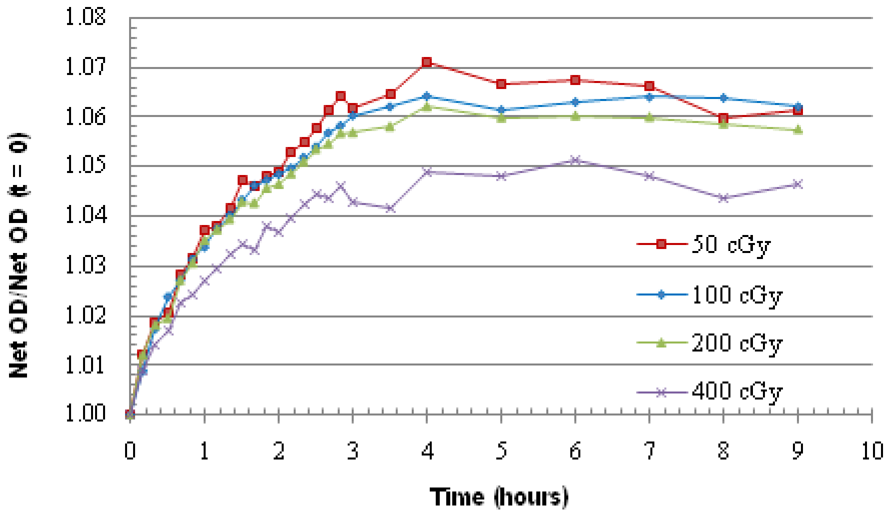


Figure 2. The stability of Gafchromic™ EBT film development for the interval of 9 hours after irradiation.

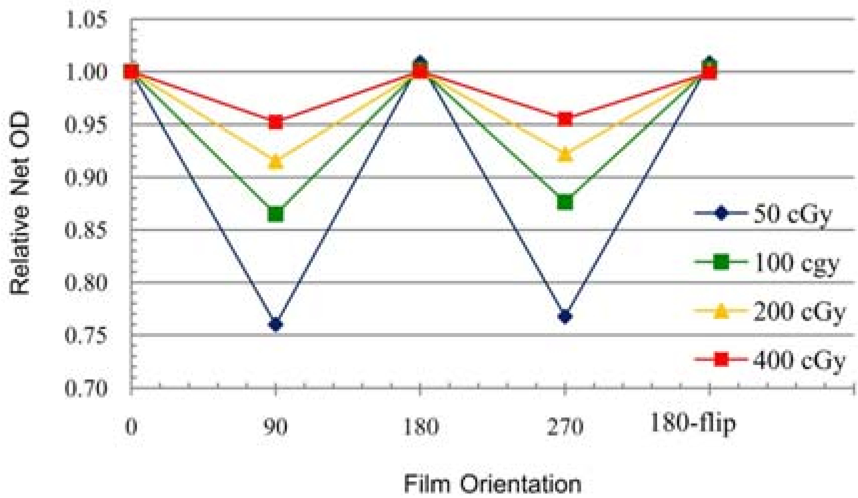


Figure 3. The response of Gafchromic™ EBT film at the position of 0^0, 90^0, 180^0, 270^0 and 180^0 - flip degree.

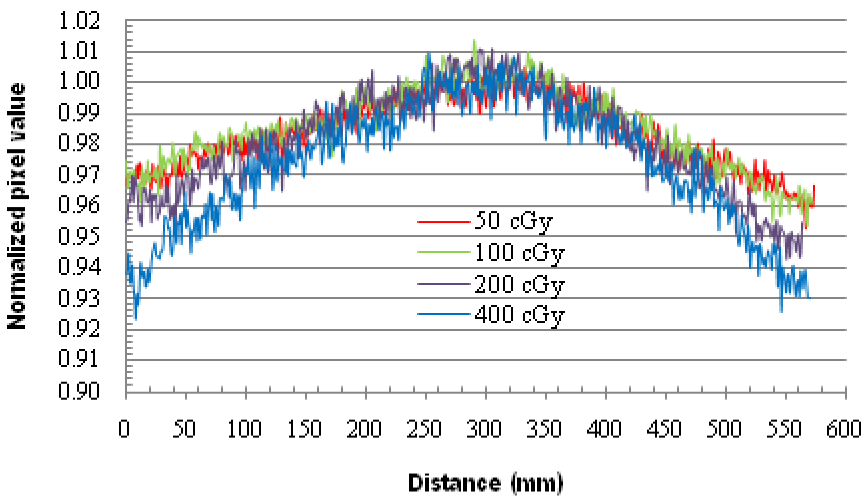


Figure 4. The non-uniformity of Gafchromic™ EBT film at various doses of 50, 100, 200, and 400 cGy.

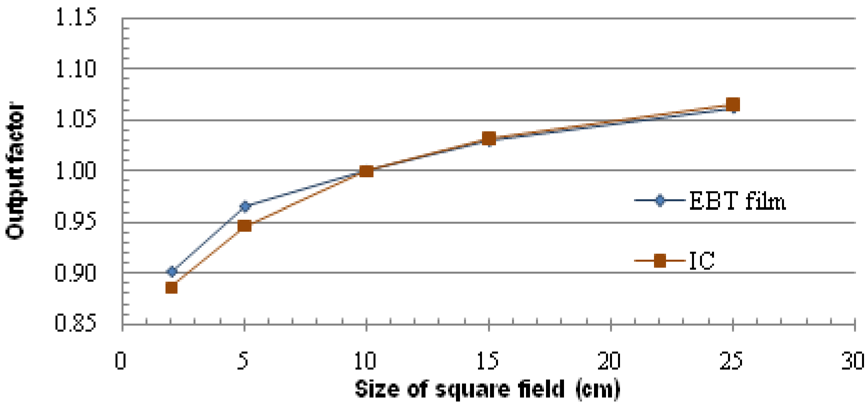


Figure 5. Output factors of 6 MV photon beams obtained by Gafchromic™ EBT film and CC13 Ionization chamber at 1.5 cm depth, 100 cm SSD.

5. Dose rate effect

The relative response of Gafchromic™ EBT film due to dose rates of 208.33 to 468.75 cGy/min normalized to 300 cGy /min showed the maximum variation about 0.3% for real time measurement and 1.0% for 24 hours after irradiated EBT film.

6. The sensitometric curve of Gafchromic™ EBT film

The sensitometric curve which is illustrated in Fig.6 was plotted between net optical densities and doses. It was shown as a third-order polynomial fitted curve. The curve changed less at doses larger than 400 cGy at net optical about 0.42 so the suitable dose range using for IMRT dose verification should not be greater than 400 cGy.

C. Percentage depth dose and beam profile

The central axis depth dose of 10 x 10 cm^2 standard field size measured by films and ionization chamber and the difference between two methods are presented in Fig.7. The difference between two methods of measurements at 5 cm depth were 3.11%, 0.64% and 1.12% for 2 x 2 cm^2, 6 x 6 cm^2 and 10 x 10 cm^2 field size, respectively.

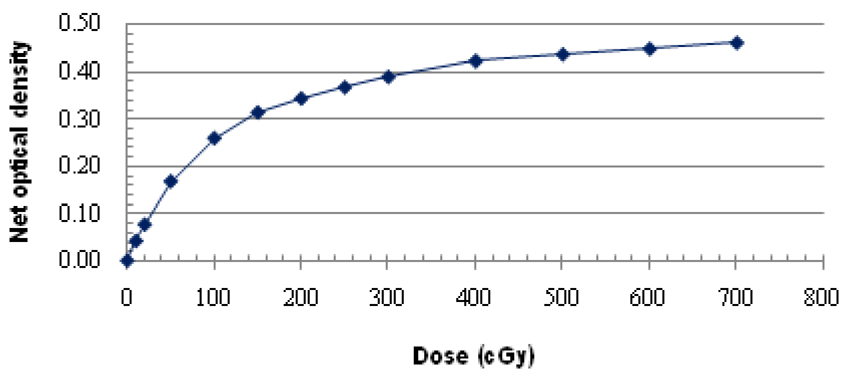


Figure 6. The sensitometric curve of Gafchromic™ EBT film at dose of 50 – 700 cGy for 10 x 10 cm^2 field size at 1.5 cm depth.

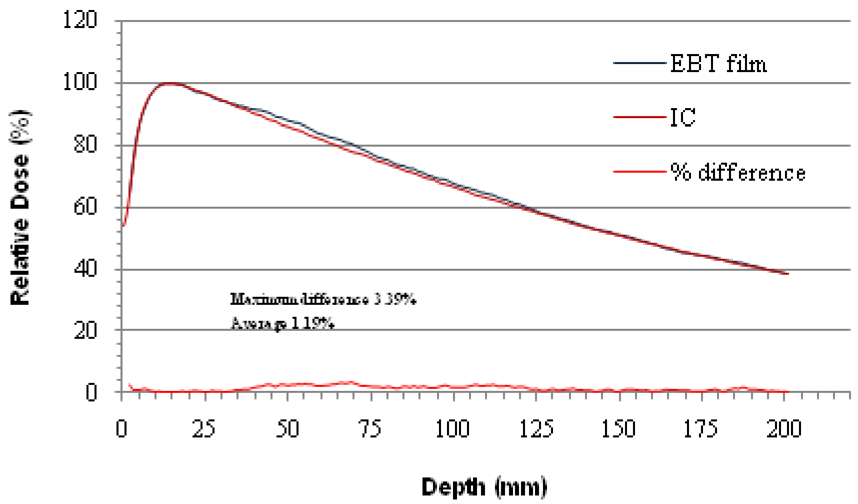


Figure 7. Comparison of percentage depth dose studied by Gafchromic™ EBT film and CC13 Ionization chamber for 10 x 10 cm^2 field size.

The beam profiles of Gafchromic™ EBT film and CC13 ionization which are shown in Fig. 8 agreed at central axis region but differed at the high dose gradient and penumbra region. The film contributed sharper dose fall off than CC13 ionization chamber due to high resolution of film.

D. Dose verification analysis

The comparison of fluence map between Gafchromic™ EBT film and calculated by Eclipse treatment planning for 3 plans is shown in Fig. 9. The agreement of two methods dose distributions was evaluated with gamma index which the evaluation value should not be excess than1 for 3% dose difference and 3 mm of distance to agreement. In this study, two IMRT plans of a nasopharynx cancer showed 82.5% and 90.6% passed for plan one and plan two, respectively. The IMRT plan of a brain tumor showed 97.8% passed. The values of percentage of failure occurred at high dose gradient region because the high resolution of EBT film can detect dose distribution better than computed calculation.

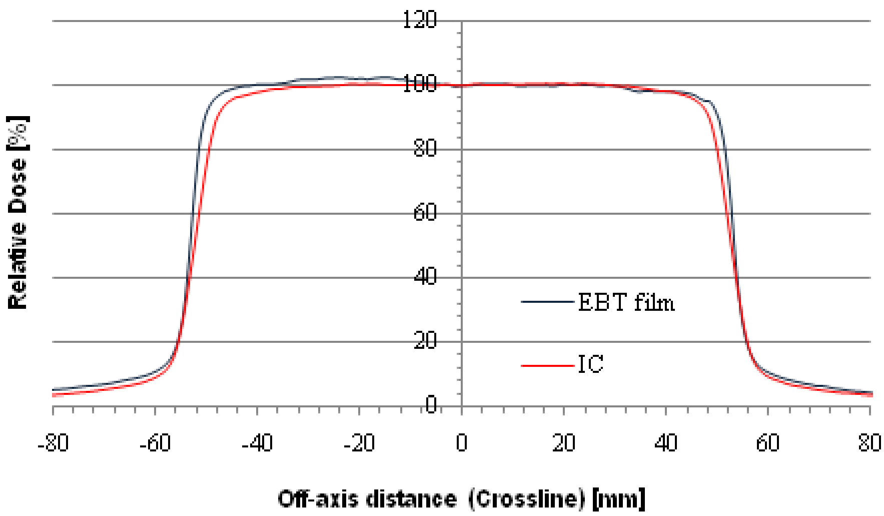
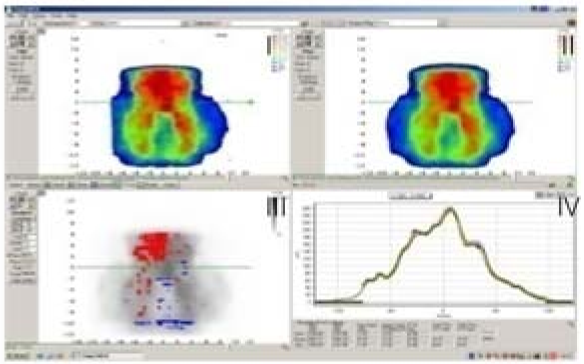
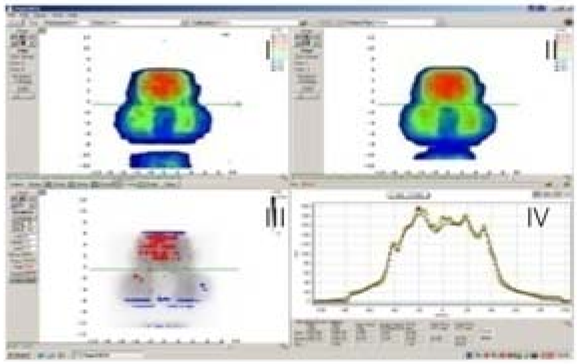


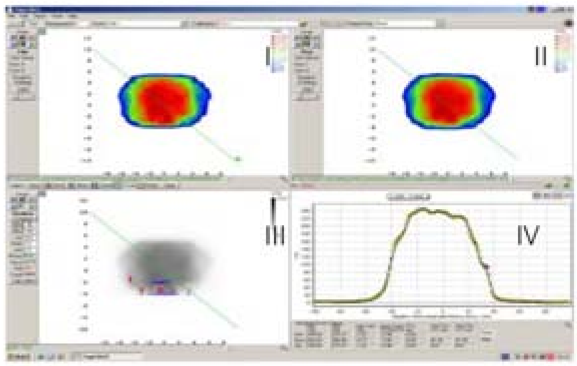
Figure 8. Comparison of beam profile obtained by Gafchromic™ EBT film and CC13 Ionization chamber for 10 x 10 cm^2 of field size at 5 cm depth.



a) Nasopharynx plan 1 (composite beams of 9 fields for 6 MV photon beam).



b) Nasopharynx plan 2 (composite beams of 9 fields for 6 MV photon beam).



c) Brain tumor plan 3 (composite beams of 7 fields for 6 MV photon beam).

Figure 9. The verification of dose map between Eclipse treatment planning calculation and Gafchromic™ EBT film measurement of two nasopharynx cancers and one brain tumor of plan number 1, 2 and 3 for 6 MV photon beam.

(I) Fluence map from a Gafchromic™ EBT film measurement

(II) Fluence map from Eclipse treatment planning calculation

(III) A comparison of fluence map in term of gamma index, dots represented the failure of dose and distance to agreement

(IV) A comparison of beam profile

Discussion and Conclusion

The factors influence scanner response should be examined by reading response, repeatability and reproducibility before studying the characteristics of Gafchromic™ EBT film. The warm up of scanner was performed by pre-scan without a film at least 5 times before scanning EBT film to get the stability of reading.[8,9] This was due to the reading response, repeatability and reproducibility of scanner were depending on the temperature stability. The repeatability of Epson Perfection V700 flat-bed scanner was within 1.1% which quite agreed with Van Battum LJ et al.[10] who reported 0.5% for Epson 1680 Expression Pro transmission flat-bed scanner. The variation of reproducibility was within 1.0% for five days reading corresponded to Van Battum LJ et al.[10] who found 0.3% - 0.5%. Zeidan OA et al.[6] reported 3% of scanner reproducibility using Microtek ScanMaker i900. The red channel of a tagged image file format (TIFF) was the highest sensitivity which agreed with several literatures.[8,9,11, 13] The optimized stability of film development time was about 4 hours after irradiation which increasing 7%, after that it was increased about 1.7%. The speed of Gafchromic™ EBT film development was varied with various doses which the lower doses presented more change of net optical density than higher doses. Our work agreed with Sankar A, et al.[1] who found that the percentage of density growth varied with the dose. The direction of scan was very important because the polarization effect will be affected on signal measurement which can reduce the signal up to 50%.[6] The non-uniformity of the Gafchromic™ EBT film and Epson Perfection V700 scanner was about 7% for 400 cGy which the far off-axis presented lower pixel value than the area near the central axis. The effect of non-uniformity occurred due to the light scatter of lamp scanner was interactive with active layer of film at the central axis more than off-axis. Thus, the signal measurement at the area of the central axis was higher than off-axis. This study agreed with Ferreira BC, et al.[8] and Menegotti L, et al.[4] who reported that the non-uniformity of EBT film and scanner were 6% and 9% for Epson Expression 10000 XL and Epson Perfection V750, respectively. The difference of output factor (field size factor) between Gafchromic™ EBT film and CC13 ionization chamber measurement was within 2% for field sizes of 2 x 2 cm^2 to 25 x 25 cm^2 which was higher than Van Battum L J et al.[10] who reported 0.2% of the variation of filed size factor from the ion chamber for field sizes of 4 x 4 cm^2 to 30 x 30 cm^2. The dose rate effect of the Gafchromic™ EBT film was less than 1% which agreed with the report of Rink[14] who showed about 1% dose rate effect. The sensitometric curve showed as a third-order polynomial fitted curve. The Gafchromic™ EBT film revealed the narrow net optical density range of 0.00 to 0.42 for dose 0 cGy to 400 cGy, contrast to Sankar A, et al.[1] who reported OD range of 0.42-1.02. In this study, the suitable dose range of EBT film should not be greater than 400 cGy. The difference of percentage depth dose between Gafchromic™ EBT film and CC13 ionization chamber was about 1% at 5 cm depth for 10 x 10 cm^2 field size study. The discrepancy of beam profile between Gafchromic™ EBT film and CC13 ionization chamber was presented at region of off-axis and high dose gradient. The Gafchromic™ EBT film was shown to produce acceptable agreements with the treatment planning by analyzing with the gamma index. The criterion of agreement was 90% passed which one nasopharynx cancer plan did not pass due to the complication of planning. Before implement the Gafchromic™ EBT film for dosimetric verification of advanced radiation treatment techniques, study the characteristics of film should be considered. Both of the scanner and film need to be handle carefully in order to use properly.

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