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**<원저>**

# Evaluation of DQA for Tomotherapy using 3D Volumetric Phantom

## - 3차원 체적팬텀을 이용한 토모치료의 Delivery Quality Assurance 평가 -

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— Abstract —

The study investigates the necessity of 3 dimensional dose distribution evaluation instead of point dose and 2 dimensional dose distribution evaluation. Treatment plans were generated on the RANDO phantom to measure the precise dose distribution of the treatment site 0.5, 1, 1.5, 2, 2.5, 3 cm with the prescribed dose; 1,200 cGy, 5 fractions. Gamma analysis (3%/3 mm, 2%/2 mm) of dose distribution was evaluated with gafchromic EBT2 film and ArcCHECK phantom. The average error of absolute dose was measured at 0.76±0.59% and 1.37±0.76% in cheese phantom and ArcCHECK phantom respectively. The average passing ratio for 3%/3 mm were 97.72±0.02% and 99.26±0.01% in gafchromic EBT2 film and ArcCHECK phantom respectively. The average passing ratio for 2%/2 mm were 94.21±0.02% and 93.02±0.01% in gafchromic EBT2 film and ArcCHECK phantom respectively. There was a more accurate dose distribution of 3D volume phantom than cheese phantom in patients DQA using tomotherapy. Therefor it should be evaluated simultaneously 3 dimensional dose evaluation on target and peripheral area in rotational radiotherapy such as tomotherapy.

**Key words:** DQA, tomotherapy, 3D volume phantom, 3D dose evaluation

## Ⅰ. INTRODUCTION

The use of 3D imaging such as tomotherapy, gamma-knife, intensity-modulated radiotherapy (IMRT), cyber-knife and stereotactic radiosurgery has been markedly increased recently in the field of radiotherapy[(1)]. Tomotherapy among them, unlike IMRT using the fixed beams, uses beam which intensity is controlled during the rotation. The dose distribution of tomotherapy is characterized by a 360° rotation of the gantry, accompanied by the irradiation from 51 directions in a single-session of the rotation. Because these mechanical characteristics of the equipment, treatment plans of tomotherapy presented an excellent result for conformality, homogeneity and the protection of the normal tissue as compared with a conventional type of IMRT treatment plans. In rotational radiotherapy including the tomotherapy, however, there is an overall distribution of a low-dose area around the target sites. If there is a great amount of the prescription dose like radiosurgery, the treatment dose in a low-dose field is also found to be relatively higher. Hence, the calculation and measurement of the treatment dose in

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these peripheral areas are as important as the accuracy of the target sites[2,3].

An accurate and systematic quality assurance (QA) is necessary for the successful performance of radiotherapy. It is classified into the QA associated with the treatment equipment and plan and patient delivery quality assurance (DQA). Equipment QA relates to radiotherapy equipment including multileaf collimator and has connection with systematic errors. To minimize these errors, regular QA is needed. Moreover, the patient DQA must proceed obligatorily for the prediction and prevention of errors that might arise from the radiotherapy of patients. Prior to the radiotherapy, patient DQA can be classified into two classes. First, the same beam as the actual treatment is applied to the phantom depending on the methods of the irradiation. Second, individual analysis depending on each irradiation was performed. In addition, there are mainly using absolute dose evaluation of measuring point dose to the target of radiotherapy and the relative dose evaluation of the treatment plans for radiotherapy[4-7].

Radiographies film was generally used for the 2-dimensional dose analysis because it has advantages which is a higher spatial resolution for the dose analysis of beam and are possible to perform the measurement for large field by one irradiation and such as low cost. But there are also problems that can't be checked the real-time availability for measurement results and a variety of variations arising in photographic developing[8]. Recently, the studies have been conducted using 2D ionization chamber array and 2D diode array according as the interest is increasing for the simplification and the accurate measurement of QA. Both studies are valuable in promptly performing the measurement and real-time analysis without photographic developing. But the 2D ionization chamber array remains at the weak point for the dose measurement of radiotherapy where there are marked changes in the dose perturbation because it has a lower resolution. The 2D diode array shows limitations such as a data loss in the lateral beam of the target. These equipment are mainly used for the 2-dimensional dose measurement on the plane. They, however, still show limitation on the accurate dose measurement in overall radiological areas[9,10]. Furthermore, the 3D dose measurement has been performed using a polymer gel and MRI until recently for the assessment of dose distribution in the overall areas where irradiations are applied. The methods of dose analysis using gel could be visually confirmed transparent gel such as a white cloud because microscopic particles of gel would be scattered if there are irradiations in tissue equivalent gel. Depending on the procedure of the analysis, however, at least 24 hours are required for the measurement time of MRI and the result of dose measurement. It remains as the major weakness. Moreover, it is also possible that there might be a serious measurement error depending on the accuracy of the image fusion[11]. To overcome these limitations, various, 3D volume phantoms have been developed, including Delta4 phantom (Scandidos, Uppsala, Sweden), Octavius (PTW, Freiburg, Germery) and ArcCHECK™(Sun Nuclear, USA). In particular, the ArcCHECK™ phantom has been fabricated as a cylinder shape. Thus, it is able to measure the beams to multiple directions. Moreover, it is also useful in 3D assessing dose measurement of arc therapy such as conventional IMRT, VMAT, Rapid Arc and Tomotherapy[12-14]. Currently, these methods for dose measurement in radiotherapy are widely used. In recent years, however, there has been increased work load for the patient DQA according to developed novel methods of radiotherapy. To improve these shortcomings, there has also been an increase interest in the reproduction of the accurate QA technology. In addition, the efficient patient DQA should be possible that simple operation and short time for analysis alongside with an accurate ability dose verification. In this study, we performed an assessment accuracy of dose evaluation and necessity of patient DQA using the evaluation of the point dose using ion chamber and the evaluation of the dose using the 3D volume phantom instead of film in radiosurgery with tomotherapy.

# Ⅱ. MATERIALS AND METHODS

## 1. Treatment plans

For the assessment of patient DQA using 3D volume phantom, the tomotherapy (Accuray, Hi ART, USA) was used. To establish the treatment plans for the assessment of patient DQA, the RANDO phantom (Radiology Support Devices, USA) and CT (Light Speed™RT16, GE, USA) to set 1.25 mm slice thickness were followed by the image acquisition. The volume of interest (VOI) was drawn with a globular shape which diameter is 0.5, 1, 1.5, 2, 2.5 and 3 cm respectively in RANDO phantom. This was followed by the transmission of prescription dose 1,200 cGy at target volume 95%. The reverse direction treatment plans were established using planning station 4.0.4 (Accuray, Hi ART, USA), setting the following conditions: the field width 1.05 cm, MP (modulation factor) 2.5, pitch 0.123 and calculation grid is fine. The volume of target was set at 0.06, 0.51, 1.70, 4.05, 8.01 and 13.64 cc. To perform the patient DQA, treatment plans calculated in the RANDO phantom were mapped onto the cheese phantom and ArcCHECK phantom, respectively. This was followed calculation of dose once again (Fig. 1, Table 1).

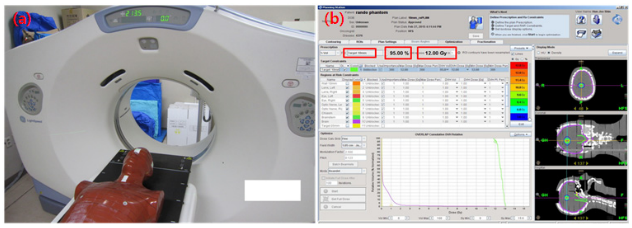


**Fig. 1** Treatment plans for a RANDO phantom. (a) RANDO phantom scan (b) 1.2Gy prescription dose at 95% of target volume

**Table 1** Absolute dose conversions of DQA for cheese phantom and ArcCHECK phantom

| Target size diameter (㎝) | Volume (cc) | Absolute dose (Gy) | |
|---|---|---|---|
| | | Cheese phantom | ArcCHECK |
| 0.5 | 0.06 | 8.641 | 9.209 |
| 1.0 | 0.51 | 9.126 | 9.848 |
| 1.5 | 1.70 | 8.675 | 9.140 |
| 2.0 | 4.05 | 8.624 | 9.087 |
| 2.5 | 8.01 | 8.661 | 9.152 |
| 3.0 | 13.64 | 8.739 | 9.240 |

## 2. Equipment for the measurement

To measure the absolute dose of the phantom, ion chamber (A1SL, Standard Imaging, USA), micro ion chamber (Exradin A16, Standard Imaging, USA) and tomoelectrometer (Standard Imaging, USA) were used. Gafchromic EBT2 film (International specialty products, Wayne, USA) was attached to a cheese phantom for the 2-dimensional evaluation of dose distribution. The measured film was digitized using VIDER scanner (VXR-16. Vider System. USA). In addition, the ArcCHECK phantom (Sun nuclear, USA) was used for the 3D measurement of dose distribution. CT scan imaging of ArcCHECK phantom and contoured DICOM RT files for imaging of treatment plans was mapped. This was followed by the calculation of dose distribution in the areas where a diode was located. Thus, it was spread with a diode map. Thereafter, the dose evaluation was assessed following a comparative analysis of dose distribution based on the treatment plans depending on the correlation with dose of the measured diode (Fig. 2, 3).

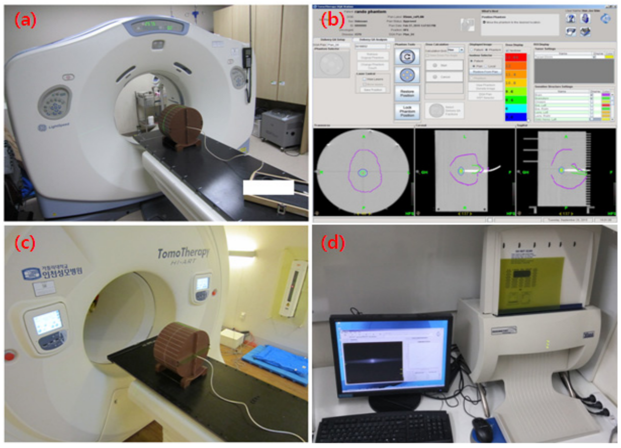


**Fig. 2** Patient DQA using cheese phantom with gafchromic EBT2 film in tomotherapy. (a) Scan of cheese phantom (b) Mapping of cheese phantom (c) Measurement cheese phantom with film (d) Scan of film

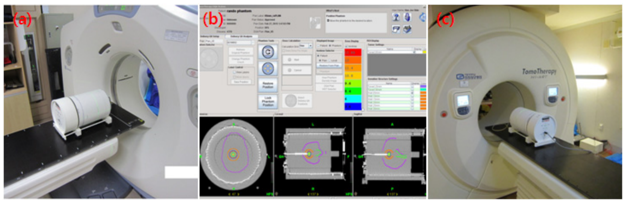


**Fig. 3** Patient DQA using ArcCHECK phantom. (a) CT scans of ArcCHECK phantom (b) Mapping of ArcCHECK phantom (c) Measurement dose distribution of ArcCHECK phantom

### 3. The evaluation of the dose calculation accuracy

To assess the accuracy in measuring the absolute dose for Cheese phantom and ArcCHECK phantom, each phantom was compared to the values of dose at the same locations as well as measurements obtained from the irradiated volume in the areas where an ion chamber was placed. The measurement using two phantoms was repeatedly performed five times for each volume to validate the reproducibility. Measurements of the dose distribution were evaluated using analytical software of the system. The measurement of the absolute dose using an ion chamber was converted into the absorption dose according to the TG-51 protocol for the dose calibration[2]. The $\gamma$-index was used to evaluate a quantitative analysis of whether the agreement between the dose distribution of treatment plans and the measured one. There is an agreement between dose distribution of the treatment plans and the measured one at a $\gamma$-index of $<1$ using dual acceptance criteria method for distance-to agreement (DTA) in high-dose gradient region and dose difference in low-dose gradient region. For evaluation of whether the agreement for point dose evaluation and dose distribution for both phantoms, criteria for acceptance of 3%/3 mm and 2%/2 mm were applied. This was followed by the comparison of the gamma passing ratio of the criteria irradiation volume and the mean irradiated volume for the error measurement. Thus, the percentage of pixels that was lower than the gamma-value of 1 ($\gamma$ %<1) was analyzed (Fig.4, 5).

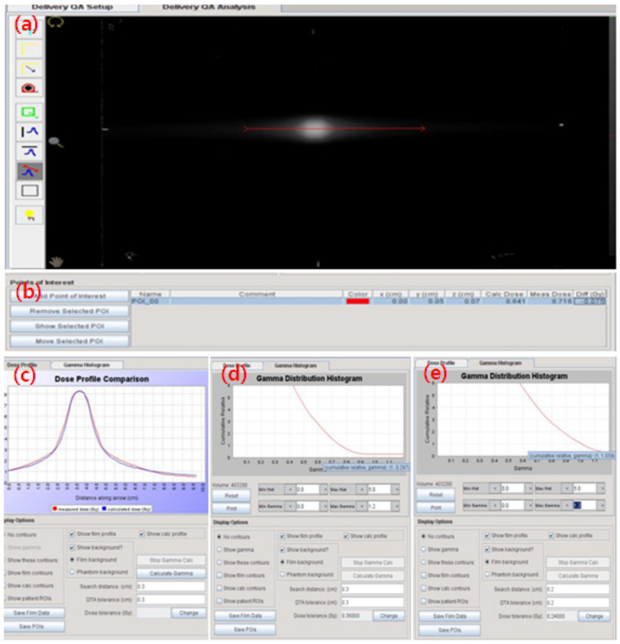


Fig. 4 Measured results using a film. (a) Film scans dose distribution (b) Point dose analysis (C) Dose profile comparison (d) Gamma passing ratio (3%/3 mm) (e) Gamma passing ratio (2%/2 mm)

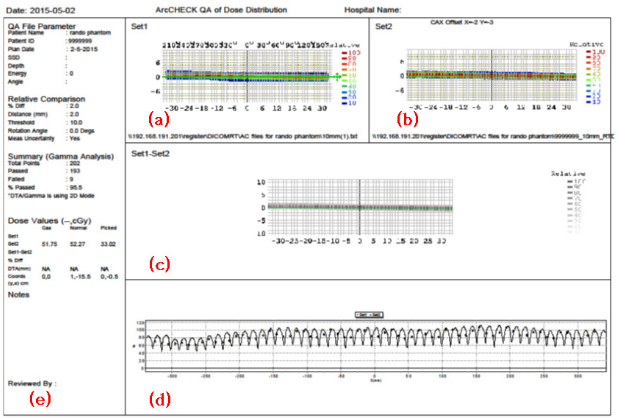


Fig. 5 Measured results using ArcCHECK. (a) Measured data. (b) RTP data (c) Fused a and b (d) Line: RTP data Dot: measurement (e) Analysis result

## III. RESULTS

Using an ion chamber, the point dose for a cheese phantom was measured. The error on the overall target was observed at 0.76±0.59%. The error was greatest value with 1.77±0.48% in the target with a diameter of 0.5 cm. In addition, it was the lowest value to 0.28±0.24% at a diameter of 2.5 cm. Following the measurement of the point dose for the ArcCHECK phantom, the overall error of the target was 1.37±0.76%. The error was greatest value with 1.88±0.54% in the target with a diameter of 1.5 cm. In addition, it was the lowest value with 0.63±0.38% at a diameter of 1.0 cm. Thus, it was confirmed that the rate of error of the prescribed dose and the measured dose for the Cheese phantom and

ArcCHECK phantom was within the range of the error (3%) (Fig. 6).

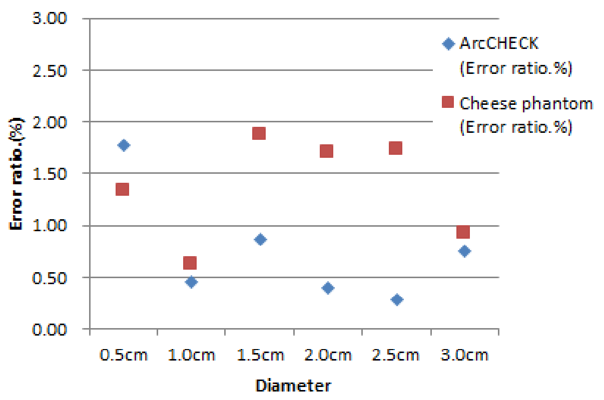


Fig. 6 Error ratio of target size for the point dose

The evaluation of dose distribution was assessed using gafchromic EBT2 film and ArcCHECK phantom. The passing ratio at 3%/3 mm was 99.26±0.01% in the ArcCHECK phantom. Moreover, the passing ratio at 3%/3 mm was 97.72±0.02% of the gafchromic EBT2 film. This showed that the passing ratio was higher in the ArcCHECK phantom compared to the gafchromic EBT2 film. The passing ratio at 2%/2 mm was 94.21±0.02% of the gafchromic EBT2 film, which was higher than 93.02±0.01% seen in the ArcCHECK phantom. The standard deviation of the passing ratio was greater in the gafchromic EBT2 film as compared with the ArcCHECK phantom (Fig.7, 8).

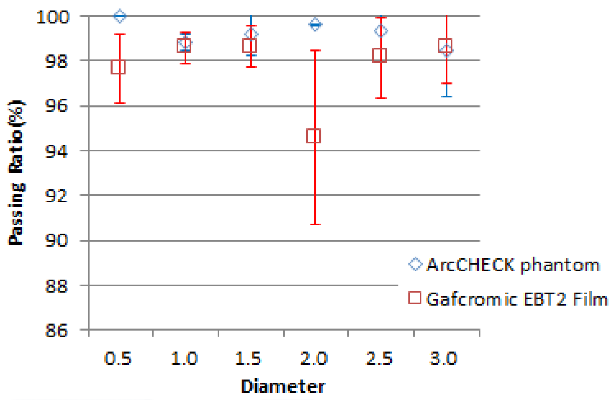


Fig. 7 Gafchromic EBT2 film and ArcCHECK phantom of the gamma correction (passing ratio, 3%/3 mm) represents

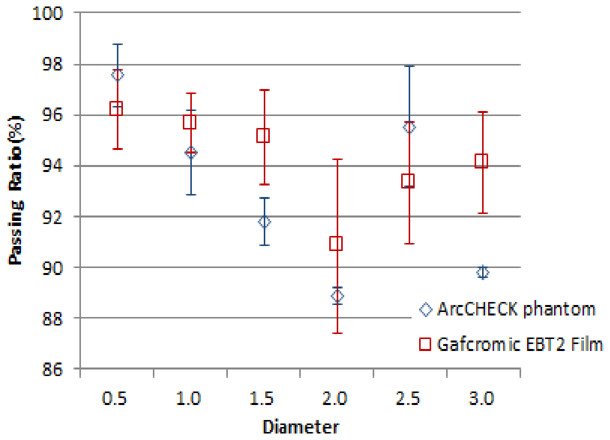


Fig. 8 Gafchromic EBT2 film and ArcCHECK phantom of the gamma correction (passing ratio, 2%/2 mm) represents

## Ⅳ. DISCUSSION

The calculation and measurement of dose in the peripheral areas are as important as the accuracy of target sites in rotational radiotherapy such as tomotherapy[15]. Depending on the methods of irradiation, each patient DQA of IMRT is classified into the evaluation of the integrated dose distribution and the evaluation of individual irradiation. However, each patient DQA in tomotherapy is evaluated through an analysis of the integrated dose distribution according to radiotherapy property.

In this study, the absolute and relative dose was evaluated using cheese phantom and ArcCHECK phantom for the assessment of patient DQA in tomotherapy. Following the measurement depending on the size of the target, it confirmed that the error ratio (3%) was within the range of the mean error. Moreover, the assessment of $\gamma$-index, served as a relative dose evaluation, showed that the mean passing ratio was 94.58% at 3%/3 mm and a target size of 2.0 cm in the gafchromic EBT2 film. Thus, mean passing ratio was lower than 95% and standard deviation was 0.0386, being the greatest value. The mean passing ratio was 96.91 at 2%/2 mm, diameter of 0.5 cm, being the greatest value. At a diameter of 2 cm, it was 90.84%, being the smallest value. Thus, the mean passing ratio was higher than 90%.

Following the assessment of γ-index using the ArcCHECK phantom, the mean value was 99.24% at 3%/3 mm and 93.02% at 2%/2 mm. The standard deviation in the assessment of γ-index was 0.0174 at 3%/3 mm and 0.00207 at 2%/2 mm on the gafchromic EBT2 film. The standard deviation was 0.0069 and 0.0112 respectively in ArcCHECK phantom. This indicates that the gafchormic EBT2 film had a relatively greater standard deviation.

As a result of this assessment, it was found that gafchormic EBT2 film had a higher degree of passing ratio. However, there are limitations in measurement range because dose distribution evaluated on a certain plane where the gafchormic EBT2 film is located instead of confirming the overall dose distribution in rotational radiotherapy. In addition, the standard deviation was relatively greater in the gafchormic EBT2 film as compared with ArcCHECK phantom. In association with this, it is difficult to perform an accurate setting due to the characteristics of dose evaluation of gafchormic EBT2 film. There are also problems with the directionality that may arise during scanning of gafchormic EBT2 film and with a lower degree of reproducibility in setting an equipment for the dose evaluation. Furthermore, the secondary contamination and the photographic density of the gafchormic EBT2 film might also be involved in this phenomenon.

## Ⅴ. CONCLUSIONS

In this study, with regards to the measurement using cheese phantom and ArcCHECK phantom in radiosurgery using the characteristics of rotational radiotherapy, the accuracy and the requirement for the absolute and relative dose evaluation were examined. In the patient DQA using tomotherapy, the assessment using a cheese phantom and gafchormic EBT2 film is disadvantageous in accurately confirming 3D measurement of dose distribution in the peripheral and target areas. In the assessment using ArcCHECK phantom, however, it is possible to perform an accurate measurement of peripheral areas of the target and real-time assessment. This can promote more accurate, faster radiotherapy for patients. Therefore, it is also presumed that 3D dose evaluation of rotational radiotherapy, leading to the concurrent assessment of both target areas and the overall irradiation areas, will provide a more accurate dose evaluation.

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•국문초록

# 3차원 체적팬텀을 이용한 토모치료의 Delivery Quality Assurance 평가

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토모를 이용한 회전 방사선치료 시 2차원적인 선량분포 평가 대신 3차원적 선량분포 평가의 필요성에 관하여 연구하였다. 토모 치료 부위의 정확한 선량분포를 측정하기 위하여 RANDO phantom을 이용하였으며, 평가 대조군으로 gafchromic EBT2 필름의 선량분포와 3차원 체적팬텀인 ArcCHECK phantom을 이용하여 3차원적인 선량분포를 gamma correction(3%/3 mm, 2%/2 mm)으로 평가하였다. 팬텀에 대한 치료 영역은 각각 0.5, 1, 1.5, 2, 2.5, 3 ㎝로 설정하였으며, 처방선량을 1,200 cGy로 하여 5회씩 선량을 조사하였다.

Gafchromic EBT2 필름을 이용한 절대선량 측정 시 평균오차는 0.76±0.59%이었으며, ArcCHECK phantom을 이용한 절대선량 측정 시 평균오차는 1.37±0.76%로 나타났다. 선량분포의 평가에서 gafchromic EBT2 필름인 경우 gamma correction(3%/3 mm)은 평균 97.72±0.02%, ArcCHECK phantom인 경우 평균 99.26±0.01%로 측정되었다. 또한 gafchro mic EBT2 필름에서 gamma correction(2%/2 mm)의 평균은 94.21±0.02%이며, ArcCHECK phantom에서는 평균은 93.02±0.01%로 측정되었다.

토모치료를 이용한 환자 DQA에서 3차원 체적팬텀인 ArcCHECK phantom을 이용한 선량분포 평가가 cheese phantom을 이용한 선량분포 평가에 비하여 치료영역 주변부에 대한 정확한 측정과 실시간 평가가 가능하므로 환자의 치료가 보다 더 정확하고 빨리 이루어질 수 있을 것으로 사료된다.

**중심 단어 :** DQA, 토모치료, 3차원 체적팬텀, 3차원 선량평가