Evaluation of 3DVH Software for the Patient Dose Analysis in TomoTherapy

Ju-Young Song*, Yong-Hyeob Kim[†], Jae-Uk Jeong[†], Mee Sun Yoon*, Sung-Ja Ahn*, Woong-Ki Chung*, Taek-Keun Nam*

*Department of Radiation Oncology, Chonnam National University Medical School, Gwangju,
[†]Department of Radiation Oncology, Chonnam National University Hwasun Hospital, Hwasun, Korea

The new function of 3DVH software for dose calculation inside the patient undergoing TomoTherapy treatment by applying the measured data obtained by ArcCHECK was recently released. In this study, the dosimetric accuracy of 3DVH for the TomoTherapy DQA process was evaluated by the comparison of measured dose distribution with the dose calculated using 3DVH. The 2D diode detector array MapCHECK phantom was used for the TomoTherapy planning of virtual patient and for the measurement of the compared dose. The average pass rate of gamma evaluation between the measured dose in the MapCHECK phantom and the recalculated dose in 3DVH was 92.6±3.5%, and the error was greater than the average pass rate, 99.0±1.2%, in the gamma evaluation results with the dose calculated in TomoTherapy planning system. The error was also greater than that in the gamma evaluation results in the RapidArc analysis, which showed the average pass rate of 99.3± 0.9%. The evaluated accuracy of 3DVH software for TomoTherapy DQA process in this study seemed to have some uncertainty for the clinical use. It is recommended to perform a proper analysis before using the 3DVH software for dose recalculation of the patient in the TomoTherapy DQA process considering the initial application stage in clinical use.

Key Words: 3DVH, TomoTherapy, Delivery quality assurance (DQA), ArcCHECK, RapidArc

Introduction

Delivery quality assurance (DQA) for the verification of the dosimetric accuracy of intensity modulated radiation therapy (IMRT) and volumetric modulated arc therapy (VMAT) has been investigated in various studies.[1-3] A conventional basic procedure for DQA is the measurement of dose distribution in a phantom structure. The dosimetric errors are then analyzed by comparing the measured data with the calculated dose in a treatment planning system (TPS).

The conventional DQA process has some limitation as it measures and analyzes the dose in a phantom material and not

within the body of the patient.[4,5] In order to overcome this limitation, special softwares were developed for calculation of the dose distribution in the patient's body using the measured data in the DQA process.[6-13] A 3DVH software (SunNuclear, Melbourne, FL) is used to calculate the dose inside the patient's body with two different methods based on the type of treatment and measurement device. One method is for the IMRT with individual fixed beams that requires per-field measurement data by using a two-dimensional (2D) diode detector array such as a MapCHECK2 (SunNuclear, Melbourne, FL). The other method is for the VMAT based on the measurement data from three-dimensional (3D) diode detector array such as an ArcCHECK (SunNuclear, Melbourne, FL).

The dosimetric accuracy of 3DVH was analyzed in various studies and showed appropriate accuracy for the IMRT with separate fixed gantry angle and for the VMAT, such as a RapidArc (Varian Medical Systems, Palo Alto, CA).

The function of 3DVH for dose calculation inside the patient undergoing TomoTherapy (Accuray, Sunnyvale, CA) treat-

ment by applying the measured data obtained by ArcCHECK was developed and recently released. Therefore, little study on the accuracy of 3DVH in the TomoTherapy DQA process has been performed. A specific analysis of the function of 3DVH for dose calculation with the Tomotherapy measurement data should be performed before applying to clinical cases.

In this study, the dosimetric accuracy of 3DVH for the TomoTherapy DQA process was evaluated in order to verify the accuracy in the application of clinical cases. For this study, the real dose distribution was measured during the Tomo-Therapy treatment and compared with the dose calculated using 3DVH. In addition, the accuracy was evaluated with the comparison results of the 3DVH application in the RapidArc DQA process.

Materials and Methods

1. Preparation of the TomoTherapy plan

The 2D diode detector array MapCHECK (SunNuclear, Melbourne, FL) was inserted in a water-equivalent MapPHAN phantom (SunNuclear, Melbourne, FL) and was used for the measurement of the TomoTherapy treatment dose, as shown in Fig. 1. After acquisition of a computed tomography (CT) image of the MapCHECK combined with the MapPHAN, a total of ten TomoTherapy plans (five prostate and five head plans) were prepared based on the CT images. The virtual target and organ at risk (OAR) were contoured differently in each plan (Fig. 2), and the TomoTherpy plans were prepared according to the dose prescription, as shown in Table 1.

2. Dose calculation with 3DVH

The DQA plans of the prepared TomoTherapy plans were made for the acquisition of measured dose data by using the ArcCHECK device. After the DQA measurement by using the ArcCHECK, as shown in Fig. 3, the error compared with the calculated dose in the TomoTherapy planning system was evaluated using the gamma evaluation method with a 3% dose difference and 3-mm distance-to-agreement criteria. The measured dose data by using the ArcCHECK was imported to 3DVH, and the 3D dose distribution in the MapCHECK phantom was recalculated. The calculated 2D coronal dose distribution at the level of diode detector array was exported in order to compare it with the dose distribution measured in the MapCHECK detector array during the TomoTherapy treatment beam delivery.
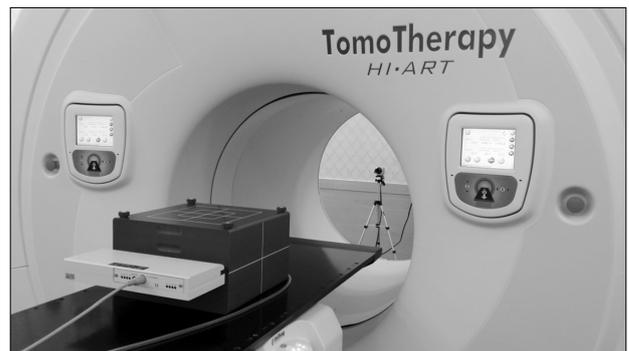
Fig. 1. MapCHECK combined with MapPHAN phantom for the dose measurement in TomoTherapy treatment.
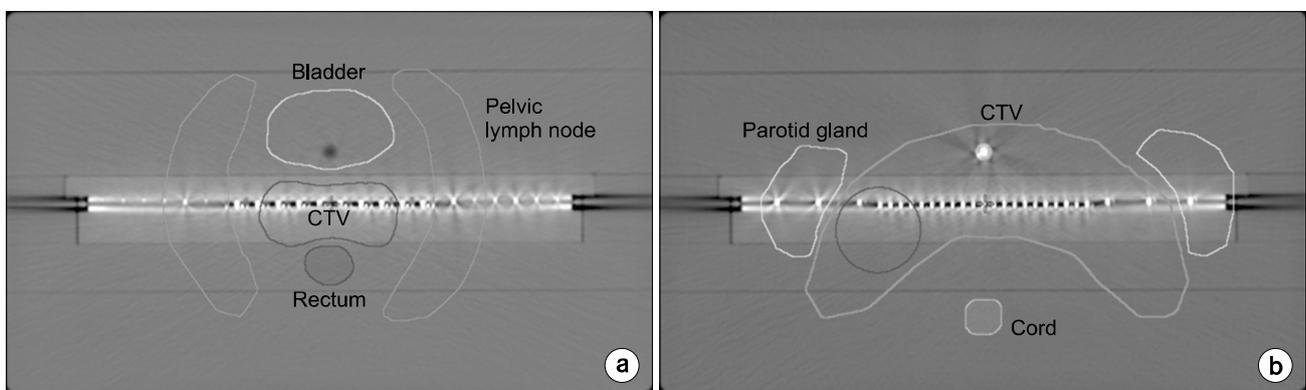

Fig. 2. Example of the contours for target and OARs delineated on the MapCHECK phantom. (a) Prostate plan, (b) Head plan.

Table 1. Dose prescription for the planning of TomoTherapy and RapidArc.

Prostate Plan	
CTV	$V_{220\ cGy} > 95\%$
Pelvic lymph node	$V_{180\ cGy} > 95\%$
Bladder	$D_{max} < 210$ cGy, $V_{140\ cGy} < 40\%$
Rectum	$D_{max} < 210$ cGy, $V_{140\ cGy} < 40\%$
Femoral head	$D_{max} < 120$ cGy, $V_{90\ cGy} < 20\%$
Head Plan	
GTV	$V_{210\ cGy} > 95\%$
CTV	$V_{180\ cGy} > 95\%$
Spinal cord	$D_{max} < 110$ cGy
Parotid gland	$D_{mean} < 65$ cGy
Thyroid gland	$D_{mean} < 90$ cGy

Fig. 4. MapCHECK combined with MapPHAN phantom for the dose measurement in RapidArc treatment.

Fig. 3. Dose measurement with ArcCHECK for the TomoTherapy delivery quality assurance (DQA).

3. Analysis on the dosimetric accuracy of 3DVH

The dose difference between the measured and calculated dose in 3DVH was evaluated using the gamma evaluation method with a 3% dose difference and 3-mm distance-to-agreement criteria.

The additional ten RapidArc plans were prepared with the same MapCHECK phantom, target, OARs and dose prescription as used in the TomoTherapy plans. The DQA plans were prepared for dose measurement by using the ArcCEHCK. After the DQA accuracy was confirmed, the measured dose data by using the ArcCHECK was imported to 3DVH for 3D dose calculation in the MapCHECK phantom. The calculated 2D coronal dose distribution at the level of MapCHECK diode detector array was exported, as in the case of the TomoTherapy analysis. The dose difference between the dose meas-

ured during RapidArc beam delivery and dose calculated in 3DVH was evaluated using the gamma evaluation method with the same criteria of the TomoTherapy case.

The Novalis Tx linear accelerator (Varian Medical Systems, Palo Alto, CA) was used, as shown in Fig. 4 and the RapidArc plans were prepared using the Eclipse (Varian Medical Systems, Palo Alto, CA) planning system. The photon energy was 6MV, which is similar to the photon energy in the TomoTherapy plans, and a single arc was used in all the RapidArc plans.

The evaluated 3DVH accuracy in the RapidArc DQA process was compared with the results in the TomoTherapy case and the suitability of the 3DVH application in the TomoTherapy DQA was examined.

Results

The calculated pass rate in the gamma evaluation of TomoTherapy DQA by using the ArcCHECK is shown in Table 2. The average pass rate was 98.3±1.2%, which proved to be the acceptable agreement between the calculated dose and the measured dose in TomoTherapy.

The results obtained by comparing the calculated dose at level of 2D diode detector array in the TomoTherapy planning system and the measured dose distribution in the MapCHECK

Table 2. The pass rate calculated by a gamma evaluation in TomoTherapy DQA process using ArcCHECK (prostate plan: A~E, head plan: F~J).

Patient	A	B	C	D	E	F	G	H	I	J	Average
Pass rate (%)	98.5	99.2	98.4	99.9	99.0	97.9	98.3	98.6	97.2	95.7	98.3±1.2

Table 3. The pass rate calculated by a gamma evaluation between a measured TomoTherapy dose in MapCHECK and a calculated dose in TomoTherapy planning system (prostate plan: A~E, head plan: F~J).

Patient	A	B	C	D	E	F	G	H	I	J	Average
Pass rate (%)	99.7	99.7	97.9	99.7	100.0	100.0	97.3	96.9	99.6	98.9	99.0±1.2

Table 4. The pass rate calculated by a gamma evaluation between a measured TomoTherapy dose in MapCHECK and a calculated dose in 3DVH (prostate plan: A~E, head plan: F~J).

Patient	A	B	C	D	E	F	G	H	I	J	Average
Pass rate (%)	98.3	95.7	91.2	87.2	95.7	87.2	92.0	93.0	92.7	93.3	92.6±3.5

Table 5. The pass rate calculated by a gamma evaluation in RapidArc DQA process using ArcCHECK (prostate plan: A~E, head plan: F~J).

Patient	A	B	C	D	E	F	G	H	I	J	Average
Pass rate (%)	98.7	98.8	99.3	97.8	99.2	99.8	100.0	99.7	99.8	99.7	99.3±0.7

Table 6. The pass rate calculated by a gamma evaluation between a measured RapidArc dose in MapCHECK and a calculated dose in Eclipse planning system (prostate plan: A~E, head plan: F~J).

Patient	A	B	C	D	E	F	G	H	I	J	Average
Pass rate (%)	98.8	99.6	100.0	99.6	99.6	99.0	100.0	99.3	98.6	100.0	99.5±0.5

Table 7. The pass rate calculated by a gamma evaluation between a measured RapidArc dose in MapCHECK and a calculated dose in 3DVH (prostate plan: A~E, head plan: F~J).

Patient	A	B	C	D	E	F	G	H	I	J	Average
Pass rate (%)	99.2	98.0	97.5	100.0	99.6	99.0	100.0	100.0	100.0	100.0	99.3±0.9

phantom are shown in Table 3. The average pass rate of the gamma evaluation was 99.0±1.2%, which was in good agreement with the calculated dose by using the TomoTherapy planning system and the measured dose.

The results of gamma evaluation between the measured dose in the MapCHECK phantom and the recalculated dose in 3DVH are shown in Table 4. The average pass rate was 92.6±

3.5%, and the error was greater than that in the gamma evaluation results with the dose calculated in TomoTherapy planning system.

The results of gamma evaluation in the RapidArc DQA process are shown in Table 5, Table 6, and Table 7. The average pass rate was 99.3±0.7% in the RapidArc DQA process using the ArcCHECK and was in good agreement. The aver-
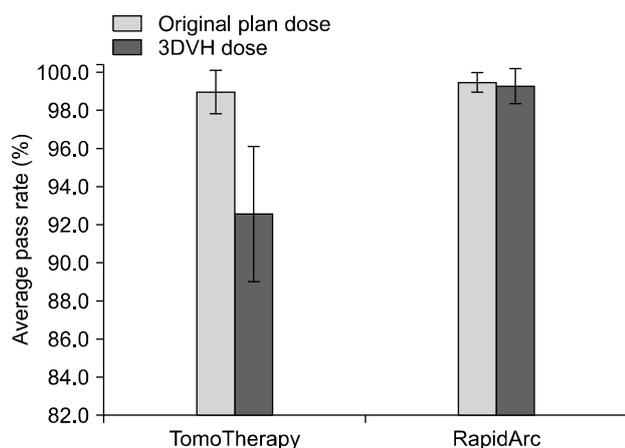
Fig. 5. Comparison of the average pass rate calculated in a gamma evaluation between a measured dose in MapCHECK and a predicted dose in each dose calculation tool.

age pass rate was 99.5±0.5% when the measured dose distribution in the MapCHECK phantom was compared with the calculated dose distribution in the Eclipse planning system. The average pass rate was 99.3±0.9% when the measured dose was compared with the recalculated dose in 3DVH, which was in good agreement and similar to the dose calculated in the Eclipse planning system.

The graph in Fig. 5 compares the evaluated results, and the increased error can be seen in the TomoTherapy dose calculated by 3DVH compared with other good agreement results.

Discussion

The 3DVH software can recalculate the dose distribution inside the body of the patient subject to a delivered treatment beam and overcome the limitation of a conventional IMRT DQA process with the phantom material. The evaluation of 3DVH in the RapidArc DQA process revealed its high accuracy in this study. Similar results in many other studies were obtained to confirm the accuracy of 3DVH in the DQA process of the IMRT and VMAT.

In this study, we mainly evaluated the dosimetric accuracy of a recently released 3DVH software for dose verification of the patient in the TomoTherapy treatment, which should be confirmed before application in real clinical cases. The evaluated results in this study showed that the accuracy of 3DVH in the TomoTherapy DQA process was not good compared

with the accuracy in the RapidArc DQA process. Although the average pass rate in gamma evaluation was greater than 99.0% in all the RapidArc analysis, the average pass rate in 3DVH evaluation in the TomoTherapy analysis was 92.6±3.5%. The average pass rate in this case is significantly lower ($p < 10^{-3}$) than the pass rate, 99.0±1.2%, in gamma evaluation with a calculated dose in the TomoTherapy plan. The inaccuracy of 3DVH in TomoTherapy was considerably large, and the deviation of the accuracy varied in each plan, which makes it difficult for applications in clinical cases.

The inaccuracy of 3DVH for TomoTherapy evaluated in this study could not be analyzed in comparison to that in other studies, because the 3DVH software for TomoTherapy had been developed and released recently and there is not enough data for evaluation. The cause of inaccuracy can be estimated with several factors. The dose calculation algorithm of 3DVH for TomoTherapy seems to be imperfect to combine the measured dose data from the ArcCHECK and TomoTherapy plan considering the large deviation in each plan. The complication of the TomoTherapy beam delivery process that integrates the movement of a treatment table and binary multi-leaf collimator (MLC) with the helical rotation of a linear accelerator (LINAC) might not be completely considered in the dose calculation algorithm of 3DVH. The accuracy of 3DVH in TomoTherapy is expected to increase as the data from many users is accumulated and a corrected dose calculation algorithm is established.

Although the evaluated inaccuracy of 3DVH in TomoTherapy might be limited to this study, it can occur in any other sites that consider insufficient application data because of the newly developed software and the lower number of TomoTherapy sites compared to the sites using a generalized LINAC based IMRT and VMAT. Therefore, it is better to perform a proper analysis before using the 3DVH software for dose recalculation of the patient in the TomoTherapy DQA process. The further study on the error analysis will be done with the additional phantom measurements data in order to find the proper method to apply the 3DVH in TomoTherapy DQA.

Conclusion

The 3DVH software for the dose recalculation inside the body of the patient in the TomoTherapy DQA process is esti-

mated to have some uncertainty like the results in this study considering the initial application in clinical cases. A proper verification study on the dosimetric accuracy should be performed by comparing the recalculated dose in the 3DVH software with the measured dose before application to a real clinical case.

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 30(8):2089-115 (2003).

2. Palta JR, Liu C, Li JG: Quality assurance of Intensity-modulated radiation therapy. Int J Radiat Oncol Biol Phys 71(1 Suppl):S108-12 (2008).

3. 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 36(11):5359-73 (2009).

4. Korevaar EW, Wauben DJ, Langendijk JA, et al: Clinical introduction of linac head-mounted 2D detector array based quality assurance system in head and neck IMRT. Radiother Oncol 100(3):446-52 (2011).

5. Nelms BE, Zhen H, Tome WA: Per-beam, planar IMRT QA passing rates do not predict relevant patient dose errors. Med Phys 38(2):1037-44 (2011).

6. Van Elmpt W, Nijsten S, Mijnheer B, et al: The next step in patient-specific QA: 3D dose verification of conformal and intensity-modulated RT based on EPID dosimetry and Monte Carlo dose calculations. Radiother Oncol 86(1):86-92 (2008).

7. Olch AJ: Evaluation of the accuracy of 3DVH software estimates of dose to virtual ion chamber and film in composite IMRT QA. Med Phys 39(1):81-6 (2012).

8. Nelms BE, Opp D, Robinson J, et al: VMAT QA: measurement-guided 4D dose reconstruction on a patient. Med Phys 39(7):4228-38 (2012).

9. Carrasco P, Jornet N, Latorre A, et al: 3D DVH-based metric analysis versus per-beam planar analysis in IMRT pretreatment verification. Med Phys 39(8):5040-9 (2012).

10. Stasi M, Bresciani S, Miranti A, et al: Pretreatment patient-specific IMRT quality assurance: a correlation study between gamma index and patient clinical dose volume histogram. Med Phys 39(12):7626-34 (2012).

11. Nakaguchi Y, Araki F, Maruyama M, et al: Dose verification of IMRT by use of a COMPASS transmission detector. Radiol Phys Technol 5(1):63-70 (2012).

12. Visser R, Wauben DJ, De Groot M, et al: Efficient and reliable 3D dose quality assurance for IMRT by combining independent dose calculations with measurements. Med Phys 40(2):021710-1-6 (2013).

13. Opp D, Nelms BE, Zhang G, et al: Validation of measurement-guided 3D VMAT dose reconstruction on a heterogeneous anthropomorphic phantom. J Appl Clin Med Phys 14(1):70-84 (2013).

토모테라피 환자 치료 선량 분석을 위한 3DVH 프로그램 평가

*전남대학교 의과대학 방사선종양학교실, †화순전남대학교병원 방사선종양학과

송주영* · 김용협† · 정재욱† · 윤미선* · 안성자* · 정웅기* · 남택근*

세기조절방사선치료의 선량정확도에 대한 품질보증 과정에서 측정된 데이터를 기반으로 실제 치료 환자 신체 내의 치료 선량분포를 재계산하여 치료계획 시 계산된 선량분포와 비교, 분석을 수행할 수 있는 프로그램들이 개발되어 임상에 사용 중에 있다. 본 연구에서는 아크첵(ArcCHECK)을 사용하여 품질보증 과정에서 측정한 토모테라피 선량 데이터를 기반으로 환자 내 치료선량 분포를 재구성할 수 있는 3DVH 프로그램의 새로운 기능 및 선량정확도를 평가하고자 하였다. 이를 위한 가상의 환자로 이차원 다이오드 검출기 배열 장치인 MapCHECK 영상을 사용하여 토모테라피 치료계획을 수립하고, 아크첵으로 선량을 측정 후 다시 3DVH를 사용하여 MapCHECK 검출기 영역의 선량분포를 재계산한 후, 실제 MapCHECK에서 측정된 선량분포와 비교하여, 그 오차를 분석하였다. 분석 결과, 측정값과 3DVH 계산값 비교를 위한 감마평가에서 평균 합격률은 92.6±3.5%로 측정값과 토모치료계획에서 계산된 선량과의 감마평가 평균 합격률 99.0±1.2% 보다 오차가 큼을 보였다. 래피드아크에서 비교한 3DVH 계산값과 측정값의 감마평가 평균 합격률 99.3±0.9%와 비교하였을 경우에도 더 큰 오차를 보여, 토모테라피에서 3DVH 선량 계산 기능을 임상에서 신뢰하고 사용하기에는 더 많은 측정 결과들의 분석과 오차 원인에 대한 분석이 수행되어야 할 것으로 생각된다.