Implementation and Evaluation of the Electron Arc Plan on a Commercial Treatment Planning System with a Pencil Beam Algorithm

Sei-Kwon Kang, Soah Park, Taejin Hwang, Kwang-Ho Cheong, Me Yeon Lee, Kyoung-Ju Kim, Do Hoon Oh, Hoonsik Bae

Department of Radiation Oncology, Hallym University College of Medicine, Seoul, Korea

Less execution of the electron arc treatment could in large part be attributed to the lack of an adequate planning system. Unlike most linear accelerators providing the electron arc mode, no commercial planning systems for the electron arc plan are available at this time. In this work, with the expectation that an easily accessible planning system could promote electron arc therapy, a commercial planning system was commissioned and evaluated for the electron arc plan. For the electron arc plan with use of a Varian 21-EX, Pinnacle3 (ver. 7.4f), with an electron pencil beam algorithm, was commissioned in which the arc consisted of multiple static fields with a fixed beam opening. Film dosimetry and point measurements were executed for the evaluation of the computation. Beam modeling was not satisfactory with the calculation of lateral profiles. Contrary to good agreement within 1% of the calculated and measured depth profiles, the calculated lateral profiles showed underestimation compared with measurements, such that the distance-to-agreement (DTA) was 5.1 mm at a 50% dose level for 6 MeV and 6.7 mm for 12 MeV with similar results for the measured depths. Point and film measurements for the humanoid phantom revealed that the delivered dose was more than the calculation by approximately 10%. The electron arc plan, based on the pencil beam algorithm, provides qualitative information for the dose distribution. Dose verification before the treatment should be mandatory.

Key Words: Electron arc plan, Pencil beam algorithm, Plan system commissioning

INTRODUCTION

For large and superficial tumors, electron arc treatment may have the advantage of a more homogeneous dose distribution compared to a stationary electron beam. The postmastectomy chest wall is one of the common sites for the electron arc, saving more volume of normal organs, such as the lungs and heart.[1,2] Bedford et al.[3] applied the electron arc technique to extensive scalp lesions and compared the results with static electron delivery and the IMRT method. The arc technique was also applied to the nasal cavity and associated nodal regions.[4]

This work was supported by the Korea Science and Engineering Foundation (KOSEF) grant funded by the Korea government (MOST) (No. 20100018223).

Submitted June 4, 2010, Accepted July 13, 2010

Corresponding Author: Do Hoon Oh, Department of Radiation Oncology, Kangdong Sacred Heart Hospital, 445, Gil-dong, Kangdong-gu, Seoul 134-701, Korea

Tel: 02)2224-2309, Fax: 02)475-8763

E-mail: thinkrun@hallym.or.kr

Electron arc therapy can be thought of as a composition of multiple static beams with a fixed angular width and interval.[5-7] However, no definite planning system for arc therapy has been reported except one (Target; General Electric Medical Systems, Waukesha, WI, USA), which is no longer available commercially.[8] Therefore, continued exercises of electron arc planning have been based on one's own in-house system.[6] The lack of a radiation planning system (RTPS) could be one reason the electron arc irradiation is not widely used, even though most linear accelerators provide an option for arc treatment.

The easiest way to do the arc planning is to exploit the existing planning system if the accuracy is acceptable or predictable. However, even with the same parameters, including energy, field size, and source-to-surface distance, the sole factor of clearance (the different applicator-end to the phantom surface distance) makes electron beams show totally different beam characteristics due to the different intervening air gap. Fig. 1 shows 6×6 cm^2 profiles from the standard and arc applicators at the same depth (1.5 cm) under a Varian machine, in which the clearance increased from 5 to 34.6 cm. The necessity of an exclusive physics machine for electron arc treatment is evident.

The purpose of this work was to present the commissioning of one of the commercial planning systems, the Pinnacle3 (Philips, ver 7.4f), for electron pseudo-arc treatment using a Varian machine (Varian Medical Systems, Palo Alto, CA, USA), and to evaluate the dosimetric accuracy of the calculation. We obtained the required data using a dedicated electron arc applicator, modeled and commissioned for the planning system. The dosimetric evaluation was also undertaken with a humanoid phantom by point measurements and film exposure.

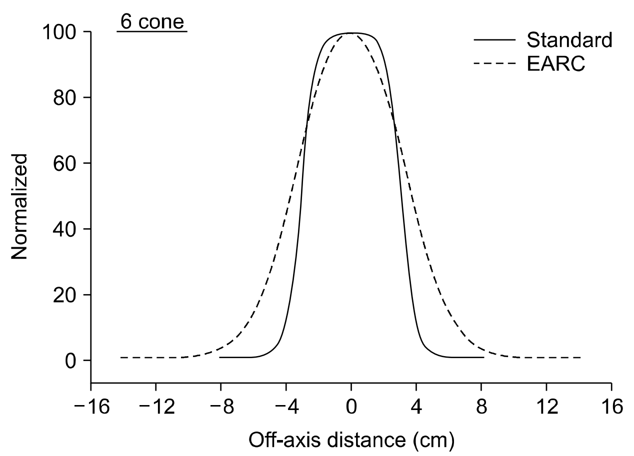


Fig. 1. Lateral profiles of a standard electron and arc applicator at a depth of 1.5 cm with 6 MeV. Both profiles are for a 6×6 cm^2 cutout. Different intervening air gaps make the profiles very different.

MATERIALS AND METHODS

A Varian 21-EX was used for electron beams (6, 9, and 12 MeV). A Varian linac was accompanied by two accessories for the electron arc treatment: a code tray and an aperture tray (Fig. 2). The code tray signals to the linac being in the electron arc mode and the aperture tray with the cutout is used to shape the beam field. The installation of both trays makes the jaw open automatically by 10×35 cm^2 (10 cm along the line connecting both side wall lasers and 35 cm parallel to the direction of the couch-gantry). The distance from the aperture tray to the isocenter is 34.6 cm while that from a standard electron applicator's tip is about 3 cm. The cutout for the arc irradiation was molded arbitrarily into the opening of 6×25 cm^2 at isocenter.

For the Pinnacle, commissioning of the electron machine requires, e.g., the depth and lateral profiles, outputs and a virtual source-to-surface distance (SSD), along with the angular scattering variance. The virtual SSD is the distance from the virtual source to the surface, in which the virtual source is de-

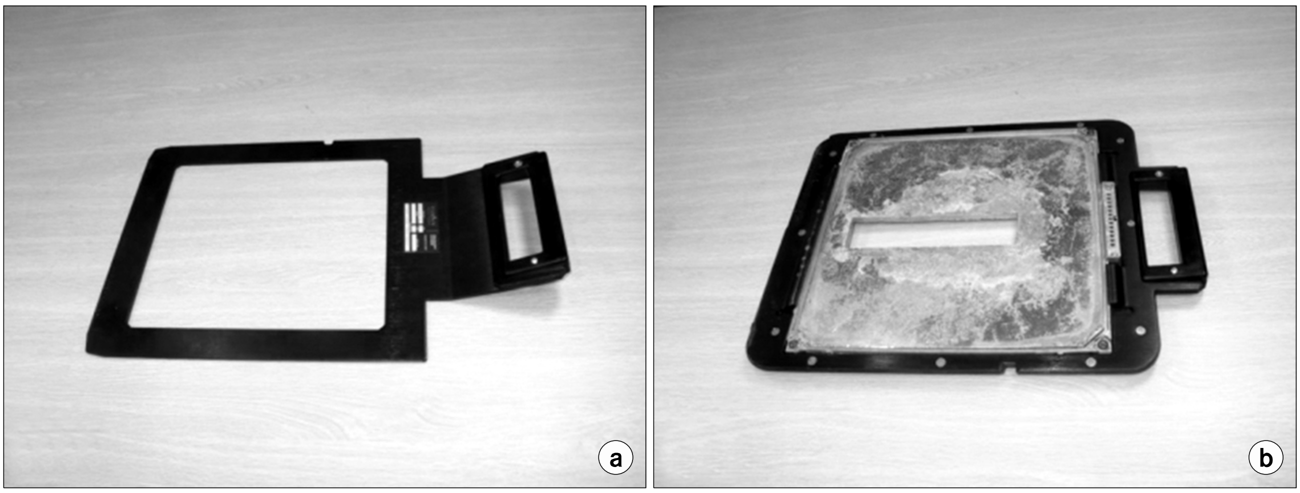


Fig. 2. Varian accessories for the electron arc treatment, (a) a code tray, and (b) an aperture tray. The code tray, which is installed just under the gantry head, signals the electron arc mode to the machine, and the aperture tray with an insert forms the exposed field.

Table 1. Data measurement parameters for the electron arc system modeling.

Parameters	Conditions
Energy	6, 9, and 12 MeV
In-air profiles	SCD=100, 105, 110, 115 and 120 cm in air with a 25 cm cutout into an arc cone.
Depth profiles (PDDs)	SSD=100 cm 10×35 cm^2 jaw with 4 and 6 cm cutouts into an arc cone 30×30 cm^2 jaw with a 25 cm cutout into an arc cone.
Cross profiles	With the same configuration of PDDs for the following depths: (1/2)R_{90}, R_{90}, R_{70}, R_{50}, and R_p+2 cm.
Output factors	10×35 cm^2 jaw with a depth of d_{max} SSD=82, 85, 90, 85, 100, 105, 110, 115, and 120 cm 4, 6, and 25 cutouts.

SCD: source to chamber distances, R_{90}: the depth of the second occurrence of the 90% dose along the central-axis depth dose, R_p: the practical range of electrons.

termined from a series of lateral profiles with shorter SSDs. The angular scattering variance accounts for the angular scattering of electrons in air. The details can be found in the user's manual.[9] In the Pinnacle, the electron arc planning mode has not been implemented. Therefore, based on the procedures in the user's manual for standard electron beam modeling, minimally required measurements were undertaken for initiation of the arc planning. Table 1 lists the measurements we made, except the common parameters, such as the cutout transmission factor, which is also needed for the standard electron beam calculation. Since Pinnacle demands data from square fields only, depth and lateral profiles for 4×4 cm^2 and 6×6 cm^2 cutouts in the aperture tray with a 10×35 cm^2 jaw field, and for a 25×25 cm^2 cutout with a 30×30 cm^2 jaw were obtained. In the case of output measurements, the jaw opening was fixed to 10×35 cm^2.

Since the Pinnacle does not provide the arc plan mode, a pseudo-arc technique, i.e., multiple static beams with a fixed angular spacing, were used with an anthropomorphic phantom. From a 90° to 340° gantry angle extending 110° around the chest wall, static beams with 5° intervals and constant monitor units per each static field were applied. Upon selection of an electron arc applicator for a static beam, a 6×25 cm^2 electron field was shaped automatically on the planning system. An electron energy of 9 MeV was selected for a plan example.

Gafchromic EBT film (International Specialty Products, Wayne, NJ, USA) was used for the film dosimetry. The film was cut to fit the axial humanoid phantom surface when inserted between the phantom slabs. A flatbed film scanner is widely suggested for the EBT film scan; however, we used an existing VXR-16 DosimetryPRO film digitizer (VIDAR systems Corporation, Herndon, VA, USA). The exposed film was analyzed using a DoseLab, a freeware for film dosimetry.[10] Three MOSFET detectors (model TN-RD-60; Thomson and Nielson, Ottawa, Canada) were positioned inside the humanoid phantom to measure representative point doses and compared with the Pinnacle calculation.

RESULTS AND DISCUSSION

A physics machine was modeled using the measured data. The measured and calculated depth profiles (PDD) and lateral profiles (25×25 cm^2) are compared for 6 MeV and 12 MeV (Fig. 3). Contrary to the PDDs with an acceptable calculation accuracy of 1% for both energies, the calculated lateral profiles showed an underestimation compared to measurements, such that the distance-to-agreement (DTA) was 5.1 mm at a 50% dose level for 6 MeV and 6.7 mm for 12 MeV. For a 6×6 cm^2 field, the DTAs were 0.9 mm and 1.5 mm for 6 MeV and 12 MeV, respectively. The underestimation of the modeling could lead to an overestimation of the required monitor units for prescribed dose, resulting in an overdose beam delivery.

The modeling accuracy decreased slightly as the energy increased, except below 5% dose level, where a rapid drop to zero of the calculation occurred for 6 MeV and a relatively

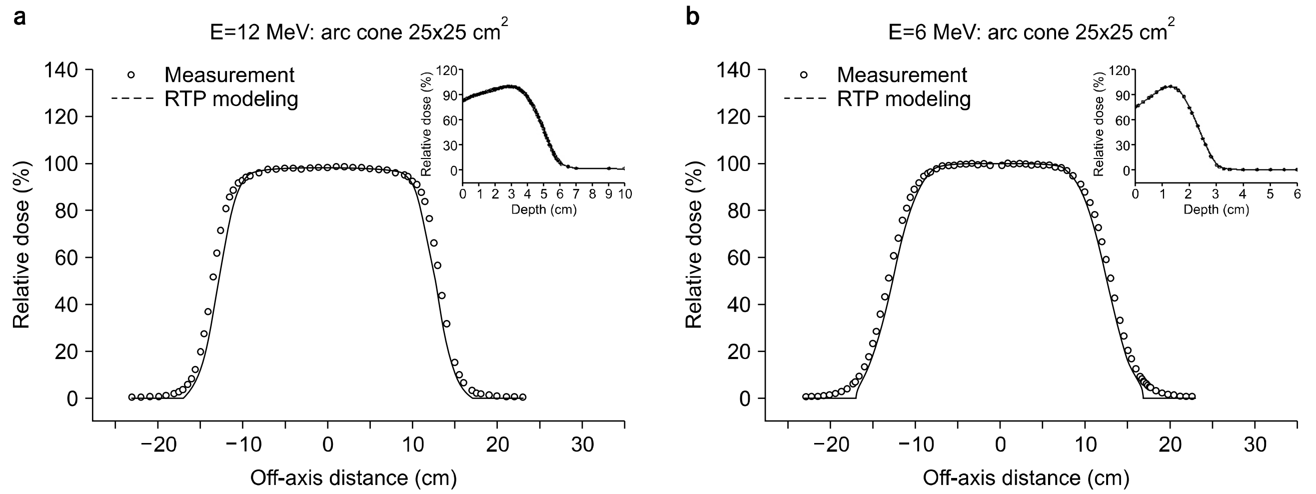


Fig. 3. Comparison of the measured and calculation in the RTPS modeling for the electron arc plan with (a) 6 MeV and (b) 12 MeV. For both energies, PDDs show acceptable agreement between measurement and calculation to within 1%; however, lateral profile calculations underestimate the measurement at the penumbra region, including the end of the profiles.

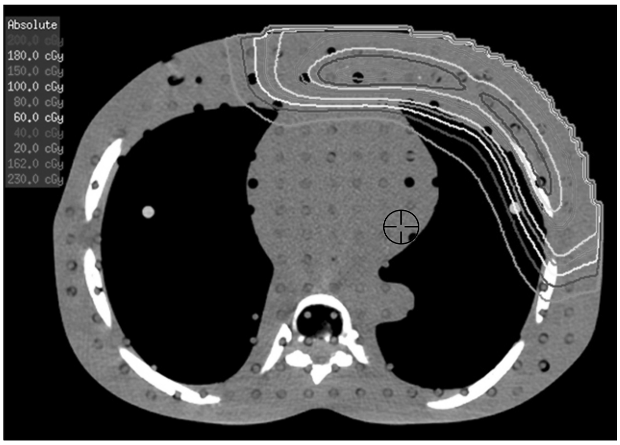
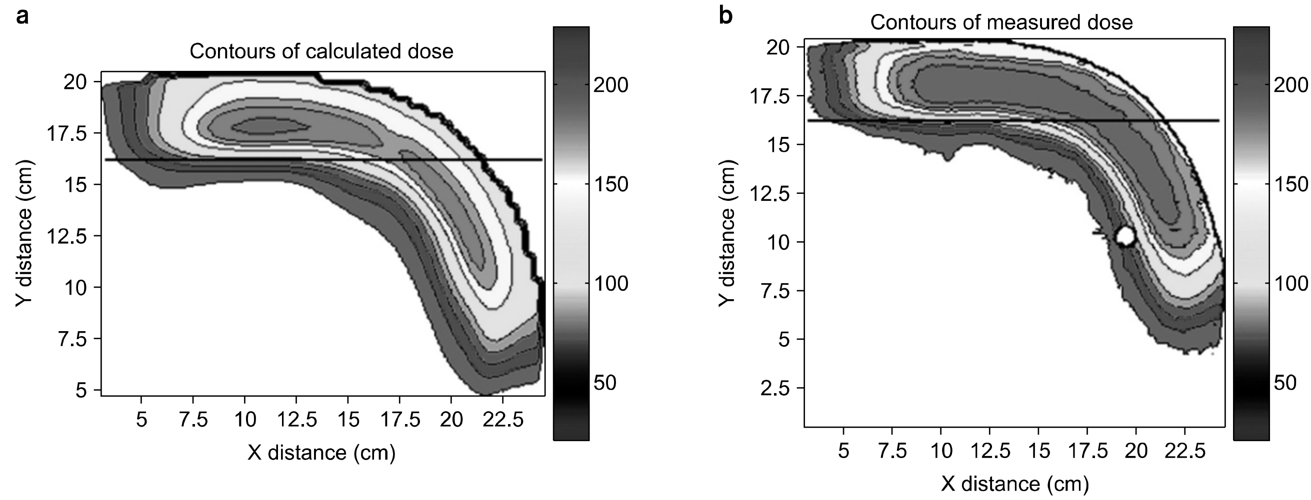


Fig. 4. An example of an electron arc plan on the commissioned planning system. The arc spans from 90° to 340° at 5° intervals.

smooth decrease for 12 MeV. The behaviors of other profiles were similar, irrespective of the measurement depth. The unusual underestimation at both ends of the profiles could be attributed to the inability of the large angle scattering modeling of the pencil beam algorithm, which was more prominent at the lower electron energy. The underestimation below the low-dose level of 5% was also reported by Chi et al.[8] during modeling for the electron arc planning system based on the pencil beam redefinition algorithm, in which a collimator width correction factor was intentionally introduced for compensation of the dose output deficit.

Fig. 4 shows one example of the electron arc plan for 9 MeV with a rotating coverage from 90° to 340°. By selecting the electron arc icon, a 6×25 cm^2 field is formed (lower left). For the dose prescription, the monitor unit was adjusted with equal weights for each beam.

The film dosimetry results are shown in Fig. 5, in which RTP calculated (a) and EBT film measured (b) dose distributions are compared along with the profiles extracted at the position of the horizontal solid lines (c). Gamma analysis resulted in an 82.8% pass rate for the 5%/3 mm criteria; however, the pass rate value here was not meaningful since the analyzed area contained large portions of the low dose region, including the unexposed. Most of the area above the 50% dose level failed the gamma test, which is clear in Fig. 5c, where a nearly 10% dose difference at the peak dose is observed. An overdose delivery of 10% was also confirmed with the MOSFET measurements at three representative positions, including the point of maximum dose. Therefore, the results of the electron arc plan from a commercial planning system with a pencil beam algorithm should be carefully employed for the clinical application. The electron dose calculation of Pinnacle uses the Hogstrom pencil-beam algorithm.[11] The relative out-



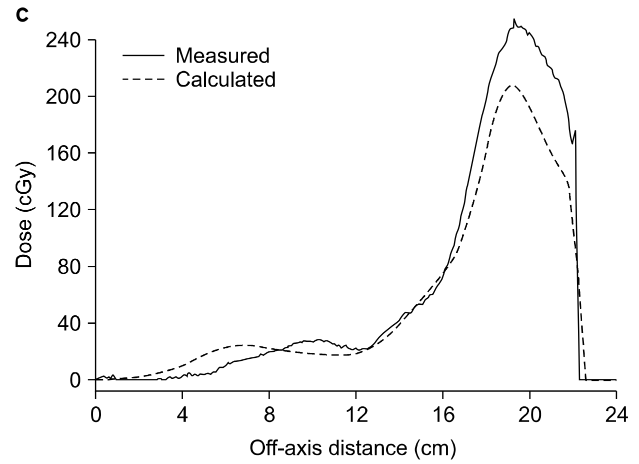


Fig. 5. Film analysis results from DoseLab; (a) calculated dose distributions, (b) measured distributions, and (c) profiles extracted at the horizontal lines of (a) and (b). A 10% overdose delivery can be seen.

put inaccuracy of the pencil beam algorithm was reported to be larger than 10% in the case of small or extremely elongated rectangular fields, depending on the energy.[12] To improve the accuracy of the calculation, adjustment of the jaw field size could be tried during the modeling stage, similar to a collimator width correction factor adopted by Chi et al.[8]

Recently, a new electron arc therapy calculation method was introduced using an electron pencil beam redefinition algorithm.[8] It has been reported that the depth dose and off-axis profiles were in good agreement to within 2% or 1∼2 mm. Another approach involves the Monte Carlo calculation. Cho et al.[13] reported the usefulness of the Monte Carlo simulation for the electron arc, in which a hybrid system consisting of the BEAM/DOSXYZ and the Pinnacle was used for the arc simulation with a Siemens machine. The tedious work of commissioning the Monte Carlo calculation for the electron arc should proceed; however, once it is established, the results would have the greatest accuracy. The dose calculation time is not a serious problem since the computing power has dramatically increased during the past several years, moreover, when the case is not the photon but the electron treatment.

The use of a commercial planning system presented here for an electron arc plan needs improvement for better accuracy. With the condition of the commercial planning system unavailable, however, the system could be useful clinically with a relative dose distribution. Dose verification before the first treatment must be performed by phantom measurements, such as IMRT QA, and a subsequent in vivo dosimetry should be fulfilled for safety.

CONCLUSION

Commissioning of a commercial planning system with the electron pencil beam algorithm was tried for the electron arc plan, in which the arc consisted of multiple static fields with a fixed beam opening. Film dosimetry along with the MOSFET measurements showed that measurements differed nearly 10% from the calculation, indicating that the plan results should be used with caution. Although the arc plan based on the pencil beam algorithm could serve as a visual guidance for the dose distribution, dose verification must proceed before each patient treatment, followed by in vivo verification.

REFERENCES

1. **Gaffney DK, Leavitt DD, Tsodikov A, et al**: Electron arc irradiation of the postmastectomy chest wall with CT treatment planning: 20-year experience. Int J Radiat Oncol Biol Phys 51:994-1001 (2001)
2. **Ung YC, Sixel KE, Bell C**: The influence of patient geometry on the selection of chest wall irradiation techniques in post-mastectomy breast cancer patients. Radiother Oncol 57:69-77 (2000)
3. **Bedford JL, Childs PJ, Hansen VN, Warrington AP, Mendes RL, Glees JP**: Treatment of extensive scalp lesions with segmental intensity-modulated photon therapy. Int J Radiat Oncol Biol Phys 62:1549-1558 (2005)
4. **Tobler M, Leavitt DD, Hayes JK**: Dosimetry and treatment planning of complex electron arc therapy: Med Dosim 20:229-235 (1995)
5. **Boyer AL, Fullerton GD, Mira JG**: An electron beam pseudoarc technique for irradiation of large areas of chest wall and other curved surfaces. Int J Radiat Oncol Biol Phys 8:1969-1974 (1982)
6. **Leavitt DD, Peacock LM, Gibbs FA Jr, Stewart JR**: Electron arc therapy: physical measurement and treatment planning techniques. Int J Radiat Oncol Biol Phys 11:987-999 (1985)
7. **Hogstrom KR, Kurup RG, Shiu AS, Starkschall G**: A two-dimensional pencil-beam algorithm for calculation of arc electron dose distributions. Phys Med Biol 34:315-341 (1989)
8. **Chi PC, Hogstrom KR, Starkschall G, Boyd RA, Tucker SL, Antolak JA**: Application of the electron pencil beam redefinition algorithm to electron arc therapy. Med Phys 33:2369-2383 (2006)
9. Electron Physics & Data Requirements. Pinnacle^3 Physics Reference Guide (2004)
10. **Childress NL, Vantreese R, Kendall R, Rosen II**: DoseLab v.4.0.0:dose comparison software package for medical physics. Houston (TX): The University of Texas M.D.Anderson Cancer Center (2004)
11. **Hogstrom KR, Mills MD, Almond PR**: Electron beam dose calculations. Phys Med Biol 26:445-459 (1981)
12. **Ding GX, Cygler JE, Yu CW, Kalach NI, Daskalov G**: A comparison of electron beam dose calculation accuracy between treatment planning systems using either a pencil beam or a Monte Carlo algorithm. Int J Radiat Oncol Biol Phys 63:622-633 (2005)
13. **Cho BC, Kang SK, Park HC, et al**: Application of Monte Carlo planning system for electron arc therapy. *Proc 14th Int Conf on the Use of Computers in Radiation Therapy*. 2004, Seoul, pp. 669-671

Pencil Beam 알고리즘 기반의 상용 치료계획 시스템을 이용한 전자선 회전 치료 계획의 구현 및 정확도 평가

한림대학교 의과대학 방사선종양학교실

강세권・박소아・황태진・정광호・이미연・김경주・오도훈・배훈식

현재 이용되고 있는 상용 치료 계획시스템은 대부분의 치료용 선형가속기가 제공하는 전자선 회전 방식의 치료 기능을 제공하지 않고 있으며, 이것은 전자선 회전 치료가 널리 이용되지 못하는 한 가지 원인이 되기도 한다. 본 연구에서는 Varian 21-EX에 대해, pencil beam 기반의 Pinnacle3 (ver. 7.4f)를 이용한 전자선 회전 치료를 위한 커미셔닝을 한 후, 치료 계획을 세웠으며, 그 정확도를 평가해 보았다. 회전 빔은 폭이 일정한 조사빔을 규칙적으로 반복해서 구현하였으며, 필름과 점 선량을 측정하였다. 치료계획 시스템의 모델링 단계에서, 측정된 깊이 선량분포는 모델링의 계산과 1% 내에서 일치하였으나, 가로 선량분포의 경우에는 모델링 계산이 측정보다 작아서, 50% 선량값을 기준으로 할 때, 6 MeV는 distance-to-agreement (DTA) 값이 5.1 mm, 12 MeV의 경우에는 6.7 mm이었다. 인체모형 팬텀을 대상으로한 점 선량 및 필름 측정의 경우, 계산과 측정은 10% 이상의 차이를 보였다. Pencil beam 기반의 전자선 회전 치료 계획은 정량적인 기준으로 삼기에는 부족해서 선량 분포에 대한 정성적인 참고에만 머물러야 하며, 환자 치료 전에 측정을 통해 선량 확인이 필요하다.

중심단어: 전자선 회전 치료계획, Pencil 빔 알고리즘, 치료계획 시스템 커미셔닝