Original Article

PMP

Progress in Medical Physics 28(2), June 2017
https://doi.org/10.14316/pmp.2017.28.2.39
pISSN 2508-4445, eISSN 2508-4453

Evaluation of Dosimetric Effect and Treatment Time by Plan Parameters for Endobronchial Brachytherapy

Chang Heon Choi*,†,‡,§, Jong Min Park*,†,‡,§, So-Yeon Park*,†,‡,§, SungHee Kang*,†,‡, Jin Dong Cho*,‡, Jung-in Kim*,†,‡

*Department of Radiation Oncology, Seoul National University Hospital, †Institute of Radiation Medicine, Seoul National University Medical Research Center, ‡Biomedical Research Institute, Seoul National University Hospital, Seoul, §Center for Convergence Research on Robotics, Advance Institutes of Convergence Technology, Suwon, Korea

Received 12 June 2017
Revised 29 June 2017
Accepted 30 June 2017

Corresponding author
Jung-in Kim
(madangin@gmail.com)
Tel: 82-2-2072-3573
Fax: 82-2-765-3317

This study aims to analyze dose distribution and treatment time of endobronchial brachytherapy (EBBT) by changing the position step size of the dwell position. A solid water phantom and an intraluminal catheter were used in the treatment plan. The treatment plans were generated for 3, 5, 7, and 10 cm treatment lengths, respectively. For each treatment length, the source position step sizes were set as 2.5, 5, and 10 mm. Three reference points were set 1 cm away from the central axis of the catheter, along the axis, for uniform dose distribution. Volumetric dose distribution was calculated to evaluate the dosimetric effect. The total radiation delivery time and total dwell time were estimated for treatment efficiency, which were increased with position step sizes. At half-life time, the differences between the position step sizes in the total radiation delivery time were 18.1, 15.4, 18.0, and 24.0 s for 3, 5, 7, and 10 cm treatment lengths, respectively. The dose distributions were more homogenous by increasing the position step sizes. The dose difference of the reference point was less than 10%. In brachytherapy, this difference can be negligible. For EBBT, the treatment time is the key factor while considering the patient status. To reduce the total treatment time, EBBT can be performed with 2.5 mm position step size.

Keywords: Endobronchial, Brachytherapy, Treatment planning, Position step size

Introduction

Extrapulmonary malignancies originate from primary or recurrent lung cancer and lung metastases from other primary sites such as colon, breast, and renal cell carcinomas.[1,2] Metastatic lesions are mainly localized in the lung parenchyma, and in rare case, in the tracheobronchial tree.[3] Most lung patients have airway obstruction due to the tumor.[4] Symptoms such as cough, dyspnea, and hemoptysis are generally reported in these patient.[5] Cryotherapy, laser therapy, photodynamic therapy, and endobronchial stent insertion are considered as curative and palliative treatments for such patients.[6,7] However, these treatments can only achieve limited clearance and short-term palliation.[8] External beam radiotherapy (EBRT) also effectively improves these symptoms.[9] A patient treated by the EBRT has high probability of side effects such as esophagitis and pneumonitis upon re-irradiation.[1,3-8,10]

Endobronchial brachytherapy (EBBT) has been known to increase the efficiency of the control of malignant airway obstruction and the duration of palliation using flexible fiber-optic bronchoscopy and high-dose-rate (HDR) afterloading brachytherapy.[4,11] The advantage of brachytherapy is that it allows safe delivery of a tumoricidal

radiation dose while avoiding radiation injury to the surrounding normal issues.[12] Additionally, the EBBT is capable of relieving debilitating symptoms such as dyspnea and hemoptysis.[4] Therefore, the quality of life of patients suffering from airway obstruction can be improved by successful palliative treatment.[13]

Most patients treated by the EBBT undergo palliative treatment and their medical status is serious or critical.[3] Moreover, in most case, the EBBT is performed under full sedation.[8] The duration of sedation is only 10 min; therefore, the total treatment time should be minimized while maintaining the prescribed dose distributions.[13-15] In practice, the treatment plan is generated beforehand for various treatment lengths; the dwell time is determined according to the prescribed dose and half-life of source.[16] The dose distribution is determined by the dwell position and the treatment time. The number of dwell position can affect to treatment time.[17] In addition, the dwell position can be changed by the source position step size. Therefore, the treatment time can be reduced by changing the source step size. Unfortunately, no report in literature has analyzed the optimization of the dwell position, treatment time, and dose distribution for various treatment lengths and prescription doses.[17]

In this study, we analyzed the dose distribution and treatment time by changing the step size of the dwell position for various treatment length. We determined the position step size to optimize the treatment time and dose distribution.

Materials and Methods

Treatment planning was performed using the Oncentra Brachytherapy treatment planning system (TPS) V. 4.3 (Nucletron B.V., Veenendaal, Netherlands) with ^{192}Ir (mHDR-v2r) source. The source was controlled by the HDR unit (MicroSelectron v3, Nucletron B.V., Veenendaal, Netherlands). At the time of planning, air kerma strength was 3.142543 and the apparent source activity was 7.70 for ^{192}Ir source. The interval between the calibration time and the treatment planning time was 47.21 days, and the decay factor was calculated as 0.642.

Lumencath® intraluminal catheter (Nucletron B.V., Veenendaal, Netherlands) was used for intraluminal brachytherapy. The catheter size was 6-French and the length was 150 cm. This catheter, with other dummy catheters, was placed on a solid water phantom for treatment planning. Two images—A-P and lateral direction—were obtained with scaler by C-arm (Ziehm Exposcope Plus C-Arm, Ziehm Imaging, Nevada, USA). These dummy catheters were used to indicate potential source positions within the phantom during the treatment planning. The possible dwell positions were determined for four treatment lengths (3, 5, 7, and 10 cm). The prescription dose was 7 Gy per fraction. Three reference points were defined to describe the prescription points. Points 1 and 3 were defined at positions 1 cm lateral to the center from the central axis of the catheters—1 cm below the start of the catheter tip and 1 cm above the end of the catheter tip, respectively. Point 2 was placed 1 cm away from the central axis of the catheters, from the middle point of the catheter length. The dose calculation was performed based on the AAPM TG-43 parameter.[18] The source position step were selected as 2.5, 5, and 10 mm for each treatment length. The dwell time, position, and the total treatment time were extracted from the plan parameter report. The total radiation delivery time, which included the source movement time for positioning, was recorded from the treatment console system. The treatment time and delivery time at planning time was corrected to time at calibration date and half-life (73.38 days) in consideration of radioactive decay.

To obtain two-dimensional dose distribution, volumetric dose calculation was performed. Then, the dose plane, which included the central axis of the catheters, was obtained.

Results

The total dwell time, dwell time per position, and the number of active positions are shown in Table 1 for each position step of the treatment length. The total dwell time during treatment planning was calculated by the product of the dwell time per position and the number of active positions. The total dwell time increased with increase in the position step size. When the position step was doubled, the dwell time per position was reduced to approximately

half and the number of active positions was reduced to exactly half, excluding the end position, i.e., the zero source position). In case of a change in the position step size from 2.5 to 10 mm, the total dwell times increased 12.5%, 7.3%, 5.4%, and 2.4% for 3, 5, 7, and 10 cm treatment lengths, respectively. The total dwell time differences at calibration date, i.e., maximum activity, were 9.6, 8.1, 7.8, and 4.7 s for 3, 5, 7, and 10 cm treatment lengths, respectively. After half-life, the time differences were double.

Table 2 shows the radiation delivery time and secondary time recoded on the treatment control system. The radiation delivery time is the total irradiation time including source transit time (i.e. source movement time) at treatment. The secondary time is the sum of the total treatment time and twice the transfer time. The radiation delivery time is longer than the total dwell time and can evaluate the actual patient treatment time in the treatment room. The average differences between the radiation delivery time and the total dwell time were 2.2±0.3, 3.7±0.4, 4.1±0.8, and 9.6±4.6 s for 3, 5, 7, and 10 cm treatment lengths, respectively. For 3 cm and 5 cm treatment lengths, the differences decreased with increase in the position step size. However, for 7 cm and 10 cm treatment lengths, the differences increased with increasing position step size. The maximum difference was 15.5 s for the 10 cm treatment length, with 10 mm position step.

Table 3 shows the doses of the three reference points. The doses at Points 1 and 3 were almost the same. The

Table 1. Dwell time and the number of active positions for various treatment lengths and position steps.

Treatment length (cm)	Source position step (mm)	Total dwell time (sec)			Dwell time per position (s)	Number of active positions
		Planning	Calibration	Half life		
3	2.5	118.3	75.9	151.8	9.1	13
	5	123.9	79.5	159.0	17.7	7
	10	133.2	85.5	171.0	33.3	4
5	2.5	172.2	110.5	221.1	8.2	21
	5	176	112.9	225.9	16.0	11
	10	184.8	118.6	237.2	30.8	6
7	2.5	226.2	145.2	290.4	7.8	29
	5	231	148.2	296.5	15.4	15
	10	238.4	153.0	306.1	29.8	8
10	2.5	311.6	200.0	400.0	7.6	41
	5	315	202.2	404.4	15.0	21
	10	319	204.7	409.5	29.0	11

Table 2. Radiation delivery time and secondary time recoded on the treatment control system for various treatment lengths and position steps.

Treatment length (cm)	Source position step (mm)	Radiation time (s)			Secondary time (s)
		Planning	Calibration	Half life	
3	2.5	120.9	77.6	155.2	131.4
	5	126.0	80.9	161.8	136.4
	10	135.0	86.7	173.3	141.6
5	2.5	176.4	113.2	226.5	186.8
	5	179.3	115.1	230.2	189.7
	10	188.4	121.0	241.9	198.8
7	2.5	229.2	147.1	294.3	239.4
	5	235.5	151.2	302.4	245.8
	10	243.2	156.1	312.3	253.5
10	2.5	315.8	202.7	405.5	326
	5	324.1	208.1	416.1	331.6
	10	334.5	214.7	429.5	334.8

average difference was 0.2. The ratio of the dose at Point 1 to that at Point 2 increased with increase in the position step size. When the source position step increased from 2.5 mm to 10 mm, the ratio increased by 5%.

The dose distribution on the TPS are shown in Fig. 1. The 100% isodose line covered the points at distances 3.7, 4.7, and 5.7 mm from the end tip (i.e., end dwell position) along the center axis of the catheter for 2.5, 5, and 10 mm source steps with all treatment lengths, respectively.

Discussion

The total dwell time increased with position step size for all treatment lengths. When the position step size was increased, the number of active positions decreased for each treatment length. The dwell time per position was increased to deliver the prescribed dose to the reference points. However, the increase rate of the dwell time per position was less than the reduction rate of the number of active positions. The total dwell time is defined as the product of the dwell time per position and the number of active positions; therefore, the total dwell time increased with increasing position step size.

The total treatment time is determined by the radiation delivery time and not the total dwell time. The average differences between the radiation delivery time and the total dwell time were increased in keeping with the treatment lengths. However, the differences between the radiation delivery time and the total dwell time show different tendencies with the source position step for the treatment length. For 3 cm and 5 cm treatment lengths, the differences decreased with decreasing source position step. However, the differences showed the opposite tendency for 7 cm and 10 cm treatment lengths.

The total travel time between the neighboring dwell positions increased with increasing position step size, because the traveling distance was increased. However, the

Table 3. Doses at three reference points for various treatment lengths and position steps.

Treatment length (cm)	Source position step (mm)	Reference point dose		
		Point 1	Point 2	Point 3
3	2.5	98.91	102.15	98.93
	5	99.11	101.76	99.13
	10	99.72	100.54	99.74
5	2.5	96.49	106.95	96.56
	5	97.02	105.88	97.09
	10	98.15	103.62	98.22
7	2.5	95.14	109.61	95.25
	5	95.81	108.28	95.91
	10	97.16	105.58	97.26
10	2.5	94.06	111.73	94.21
	5	94.80	110.25	94.94
	10	96.02	107.83	96.15

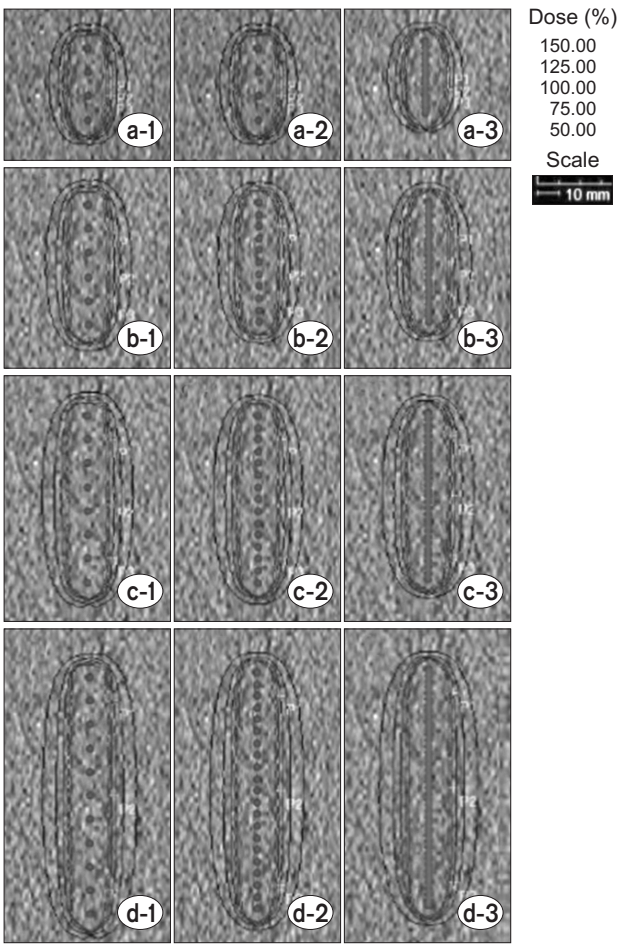

Fig. 1. Dose distribution in coronal view for each position step size and treatment length. (a-1): Position step size=2.5 mm, treatment length=3 cm; (a-2): position step size=5 mm, treatment length=3 cm; (a-3): position step size=10 mm, treatment length=3 cm; (b-1): position step size=2.5 mm, treatment length=5 cm; (b-2): position step size=5 mm, treatment length=5 cm; (b-3): position step size=10 mm, treatment length=5 cm; (c-1): position step size=2.5 mm, treatment length=7 cm; (c-2): position step size=5 mm, treatment length=7 cm; (c-3): position step size=10 mm, treatment length=7 cm; (d-1): position step size=2.5 mm, treatment length=10 cm; (d-2): position step size=5 mm, treatment length=10 cm; (d-3): position step size=10 mm, treatment length=10 cm.

source movement velocity was not constant. The maximum and minimum velocities of the source were known to be 52.0 and 17.3 cm/s, respectively[19] Furthermore, acceleration also changed.[20] Therefore, the average differences between the radiation delivery time and the total dwell time for each treatment length have no trend for position step size. In case of long treatment lengths (over 7 cm), the difference of the number of dwell position between the source position steps was ≥20. The travel time for each neighboring dwell position was relatively longer. The differences showed a significant increase for long treatment lengths.

The doses at Points 1 and 3 were almost the same because the relative locations of Points 1 and 3 were set to be the same. The dose difference between Points 1 and 3 was reduced consistently with increase in the step size for the same treatment length, but increased with increasing treatment length for the same step size. The dose distribution was more homogeneous for short treatment lengths and long position steps; however, it was not significant. Particularly, differences less than 10% could be ignored in the HDR treatment due to high dose gradient. The dose distribution could be changed over 20% per mm near the source. Usually, EBBT is a palliative treatment; therefore, the dose difference can be ignored.

In case of EBB treatment, the location of the catheter is important. When the catheter is located along the airway, the tumor is distributed in the bronchus. The physician can determine the catheter position where source was started using endoscopy and AP image of C-arm. At this time, the dose margin should be considered to cover the tumor. The real treatment length can be extended along the axial direction up to the dose margin distance.

Conclusion

A treatment plan was generated for EBBT for various treatment lengths. This procedure can reduce the total treatment time by skipping the treatment planning stage. The total treatment time is very important because most patients are under sedation or anesthesia during the treatment. The total dwell time and the radiation delivery time were calculated by changing the source position step size for various treatment lengths, and the dose distribution was also evaluated. For all treatment lengths, the total treatment time was shortest for 2.5 mm source position step size; the dose distribution was found to be more homogenous with 10 mm source position step size. The treatment time was more important factor than dose homogeneity. Therefore, we concluded that the 2.5-mm position step was most suitable for EBBT.

Acknowledgements

This study was supported by a grant from the National R&D Program for Cancer Control, Ministry of Health & Welfare, Republic of Korea (No. 1631200).

All relevant data are within the paper and its Supporting Information files. This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIP) (No.-2017M2A2A7A02020643).

Conflicts of Interest

The authors have nothing to disclose.

Availability of Data and Materials

All relevant data are within the paper and its Supporting Information files.

References

1. Donovan E, Timotin E, Farrell T, Donde B, Puksa S, Sur R. Endobronchial brachytherapy for metastasis from extrapulmonary malignancies as an effective treatment for palliation of symptoms. Brachytherapy. 2017;16:630-8.
2. Nag S, Abitbol AA, Anderson LL, Blasko JC, Flores A, Harrison LB, et al. Consensus guidelines for high dose rate remote brachytherapy in cervical, endometrial, and endobronchial tumors. Int J Radiat Oncol Biol Phys. 1993;27:1241-4.
3. Bedwinek J, Petty A, Bruton C, Sofield J, Lee L. The use of high dose rate endobronchial brachytherapy to palliate symptomatic endobronchial recurrence of previously irradiated bronchogenic carcinoma. Int J Radiat Oncol

Biol Phys. 1992;22:23-30.
4. Kelly JF, Delclos ME, Morice RC, Huaringa A, Allen PK, Komaki R. High-dose-rate endobronchial brachytherapy effectively palliates symptoms due to airway tumors: the 10-year MD Anderson cancer center experience. Int J Radiat Oncol Biol Phys. 2000;48:697-702.
5. Perol M, Caliandro R, Pommier P, Malet C, Montbarbon X, Carrie C, et al. Curative irradiation of limited endobronchial carcinomas with high-dose rate brachytherapy: results of a pilot study. Chest. 1997;111:1417-23.
6. Taulelle M, Chauvet B, Vincent P, Felix-Faure C, Buciarelli B, Garcia R, et al. High dose rate endobronchial brachytherapy: results and complications in 189 patients. Eur Respir J. 1998;11:162-8.
7. Mendiondo OA, Dillon M, Beach LJ. Endobronchial brachytherapy in the treatment of recurrent bronchogenic carcinoma. Int J Radiat Oncol Biol Phys. 1983;9:579-82.
8. Huber RM, Fischer R, Haŭtmann H, Pöllinger R, Wendt T, Müller-Wening D, et al. Palliative endobronchial brachytherapy for central lung tumors: a prospective, randomized comparison of two fractionation schedules. Chest. 1995;107:463-70.
9. Hennequin C, Tredaniel J, Chevret S, Durdux C, Dray M, Manoux D, et al. Predictive factors for late toxicity after endobronchial brachytherapy: a multivariate analysis. Int J Radiat Oncol Biol Phys. 1998;42:21-7.
10. Langendijk H, de Jong J, Tjwa M, Muller M, ten Velde G, Aaronson N, et al. External irradiation versus external irradiation plus endobronchial brachytherapy in inoperable non-small cell lung cancer: a prospective randomized study. Radiother Oncol. 2001;58:257-68.
11. Murakami N, Kobayashi K, Nakamura S, Wakita A, Okamoto H, Tsuchida K, et al. A total EQD2 greater than 85 Gy for trachea and main bronchus D2cc being associated with severe late complications after definitive endobronchial brachytherapy. Journal of Contemporary Brachytherapy. 2016;8:164.
12. Moon SY, Jeong E, Lim YK, Chung WK, Huh HD, Kim DW, et al. Feasibility Study of Source Position Verification in HDR Brachytherapy Using Scintillating Fiber. Prog Med Phys. 2016;27:213-9.
13. Delclos ME, Komaki R, Morice RC, Allen PK, Davis M, Garden A. Endobronchial brachytherapy with high-dose-rate remote afterloading for recurrent endobronchial lesions. Radiology. 1996;201:279-82.
14. Gustafson G, Vicini F, Freedman L, Johnston E, Edmundson G, Sherman S, et al. High dose rate endobronchial brachytherapy in the management of primary and recurrent bronchogenic malignancies. Cancer. 1995;75:2345-50.
15. Hosni A, Bezjak A, Rink A, Czarnecka K, McPartlin A, Patterson S, et al. High Dose Rate Brachytherapy as a Treatment Option in Endobronchial Tumors. Lung Cancer Int. 2016;2016:3086148.
16. Rogus RD, Smith MJ, Kubo HD. An equation to QA check the total treatment time for single-catheter HDR brachytherapy. Int J Radiat Oncol Biol Phys. 1998;40:245-8.
17. Wong T, Wallace S, Fernando W, Schumer W, Quong G. Dose errors in the near field of an HDR brachytherapy stepping source. Phys Med Biol. 1999;44:357.
18. Nath R, Anderson LL, Luxton G, Weaver KA, Williamson JF, Meigooni AS. Dosimetry of interstitial brachytherapy sources: recommendations of the AAPM Radiation Therapy Committee Task Group No. 43. Med Phys. 1995;22:209-34.
19. Fonseca GP, Viana RS, Podesta M, Rubo RA, Sales CP, Reniers B, et al. HDR 192Ir source speed measurements using a high speed video camera. Med Phys. 2015;42:412-5.
20. Minamisawa R, Rubo R, Seraide R, Rocha J, Almeida A. Direct measurement of instantaneous source speed for a HDR brachytherapy unit using an optical fiber based detector. Med Phys. 2010;37:5407-11.