

A Fusion Study on the Selection of Cyberknife Technique according to the Location of the Pulmonary Tumors

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폐종양의 위치에 따른 사이버나이프 기법의 선택에 관한 융합적 연구

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Abstract Depending on the location of the lung tumor, the choice of treatment technique should be considered when treating the Cyberknife. The 4DCT images of 18 lung cancer patients were analyzed, and location error values were extracted through application program. The evaluation result was lower than the average position error only in the upper and the inner. These results suggest that the Vertebral tracking technique is effective when it is close to the pulmonary attachment or near the vertebral body, and the Synchrony technique is effective at other positions. In the future, we would like to study cyber knife treatment technique according to the position of the tumor as well as the volume of the lung and the respiratory cycle.

Key Words : Cyberknife, Synchrony, Vertebral tracking, Pulmonary tumor, Position Delta Value

요 약 폐 종양의 위치에 따라 사이버나이프 치료 시 치료기법의 선택에 대해 고려해봐야 합니다. 폐암 환자 28 명을 대상으로 18개 지점에 대해 4차원 단층촬영영상을 분석하였고, 응용프로그램을 통해 위치오차값을 추출하였다. 평가 결과 상부와 내측에서만 평균 위치오차값보다 낮았다. 이러한 결과를 통해 폐첨부에 가깝거나 척추체부에 가까운 경우 척추추적기법을 적용하는 것이 효율적이며, 이외의 위치에서는 호흡동조기법이 효율적이다. 이에 본연구를 기반으로 하여 향후 폐종양의 폐내 종양의 위치뿐만 아니라 폐활량에 따른 확장범위 및 환자마다 차이가 발생하는 호흡주기에 따라 사이버나이프 치료기법을 선택할 경우 효율적인 치료기법을 선택할 수 있도록 연구하고자 한다.

주제어 : 사이버나이프, 호흡동조기법, 척추추적, 폐종양, 위치오차값

1. Introduction

Radiotherapy showed great development in the modern era. From the intensity modulated radiotherapy that can reduce the exposure dose

of the normal organ and enhance the prescription dose of the tumor, to the stereotactic radiotherapy that injects high dose through precision Radiotherapy, the image-guided radiotherapy that verifies the precise position for

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therapy, and the respiratory-tracking radiotherapy that considers the movement of the tumor from respiration, radiotherapy is applied diversely[1-8]. Among these therapies, the stereotactic radiotherapy was first developed by the Swedish doctor, Dr. Lars Leksell in 1951: narrow beams of radiation are combined in multiple directions to deliver maximum dose to the tumor. Also, minimum dose is applied to the normal organ to prevent any adverse effects, so this therapy replaced the existing multi-fraction therapy of delivering high-dose of radiation for each session. The first therapeutic apparatus applied was the gamma knife that was developed in 1968, and this therapeutic apparatus arranges the radioactive isotope of Co-60 in helmet-type to irradiate the gamma ray in multiple directions in narrow beams through the collimator[9-11]. However, this apparatus has a weakness of limiting the application only on encephalopathy such as the brain tumor and arteriovenous malformation. The therapeutic apparatus that was developed to improve this limitation and to apply the stereotactic radiotherapy on the body is Cyberknife. One comparison with the most widely used medical linear accelerator today is that a small-sized accelerator is mounted on the robot arm composed of 6 joints, so the use of the deflecting electromagnet is no longer necessary[12-14]. The Cyberknife acquired the approval from the US FDA in 2001, and as the body is occurred with the change in position due to respiration and movement of the organs, the photon of kV is used in constant interval to analyze the precise position, and the changes in the position are applied to perform the tumor-tracking therapy by using the cruise-missile-guidance technology of NASA[15-18]. The cruise-missile-guidance technology is based on the discrete time linear movement system, and uses the dynamic system model of the Kalman Filter that assumes the relation of the state vector value according to the change in time. Cyberknife using the

tumor-tracking system is divided in the therapeutic technique depending on the therapeutic site such as the head & neck and the body. Also, the body is divided in therapeutic technique according to the sites with movements, and other sites without movements[19]. In other words, the Cyberknife therapeutic technique can be divided largely into 3 techniques of Cranial tracking technique, Vertebral tracking technique and Synchrony technique. The cranial tracking technique is limited to the head, and the therapy is performed by analyzing the morphological position of the cranium, and the vertebral tracking technique enables the morphological position analysis of the vertebrae for the treatment of the tumor near the vertebrae[20]. As for the synchrony technique, when the image-guided radiotherapy is applied on the tumors with severe change from respiration including the pulmonary and hepatic tumors, the position changes each time depending on the rate of respiration, so the respiration pattern image is used and radioactive impermeable substance is inserted near the tumor to be applied in combination with the image-guided radiotherapy. In the case of applying the synchrony technique on the lungs, signifier insert is applied near the tumor for the location tracking. However, when there is migration in the signifier insert, or when the position is inappropriate to have an overlapped image, the accuracy of the synchrony technique will be degraded. Especially, when the radius of positioning is relatively high, the error will be reflected more greatly. In addition, when invasive procedure is performed for the signifier insert, there is a disadvantage of requiring a long-period of time compared to other techniques[21-23]. Lungs are the largest organ among the organs in the chest, and the weight of the lungs for adults is approximately 500~600g, with the surface area of about 90m². The total volume of the lungs is approximately 5,000~6,000cc, the respiration rate for 1 time is

300~500mL. The segments of the lungs are divided into left and right centrally of the mediastinum. The right lung has 3 lobi with 10 segments, and the left lung has 2 lobi and 8 segments[24]. Also, the movement radius of the lung tissues is different depending on the respiration. In other words, when movement is occurred on the tumor from respiration, the synchrony technique is applied to reduce the error in therapy, but when the movement radius is very low, the synchrony technique is not required. In this study, a standard is to be provided on the selection of the synchrony technique and the vertebral tracking technique according to the interval with the vertebrae.

2. Materials and Methods

2.1 Materials

The chest 4DCT images on 36 patients for the pulmonary radiotherapy in hospitals in Daejeon during October, 2015 were used as shown in Table 1. The movements in the point of interest according to the respiratory pattern had to be evaluated. 4 patients with unstable or irregular respiratory patterns, 2 patients with vertebral deformation; in the case of having vertebral deformation on selecting the point of interest in the vertebrae or lung, it becomes a factor on generating big errors on the evaluation, and 2 patients that were not set with the position on the lungs.

2.2 Methods

The measurement points are set to measure the moving distance according to respiration. However, the measurement points are set in each segment by dividing into upper, middle and lower parts due to the morphologic characteristics of the lung. For the set standard on the upper part, the central point of the No. 2 thoracic vertebrae was set as the standard, and the middle part was No. 6 thoracic vertebrae. Lastly, the central point of the No. 11 thoracic vertebrae was set on the lower part as the standard. Also, the upper, middle and lower parts were divided into left lung and right lung, and as shown in Fig. 1 to 3, 3 measurement points were set for each segment. The measurement points were set differently for each patient depending on the organ shape and body type. Therefore, in the standard of the central point of the thoracic vertebrae, in the distance increased with 5 cm from the closest distance in contact with the lung tissue, the central point of the angle enabled with the lung tissue was designated as the medial point. Also, in the standard of the central point of the thoracic vertebrae, in the distance decreased 5 cm from the longest distance in contact with the lung tissue, the central point of the angle enabled with the lung tissue was designated as the lateral point. Moreover, the central point of the angle enabled with the lung tissue in the central distance between the medial point distance and lateral point distance was designated as the center point. However, when the central point of angle was not the lung tissue,

Table 1. Information of Subject

Classification	Age	Sex	Tumor site	Tumor size	Height	Weight
Range	43 ~ 77	Female : 18 Male : 10	LUL : 6, LLL : 9 RUL : 6, RLL : 7	2 cm~5 cm	158 cm~178 cm	52 kg~80 kg
Average	61.2	-	-	3.17 cm	164.7 cm	69.8 kg
Standard Deviation	9.8	-	-	1.1	5.9	7.9

the point relevant to the lung tissue among the closest angles was set. For the moving distance measurement of each measurement point that was set, the movement according to the respiration pattern on the CT console was replayed repeatedly, and the moving distance of the particular bronchial tube on the relevant point was reflected by indicating the distance through the measure on the console. As shown in Formula (1), the moving distance was calculated through the Vector Calculation on Craniocaudal, Anteriorposterior and Mediolateral.

$$R_{tot} = \sqrt{\{(R_{vrt})^2 + (R_{lng})^2 + (R_{lat})^2\}} \quad \text{Eq. (1)}$$

- R_{tot} : Total motion range
- R_{vrt} : Anteriorposterior axis motion range
- R_{lng} : Craniocaudal axis motion range
- R_{lat} : Mediolateral axis motion range

In the standard of the moving distance according to the respiration pattern for each measurement point, the error value PDVs on the radiotherapy with Cyberknife in Fig. 4 were compared to evaluate the usefulness of the vertebral tracking technique and the synchrony technique for each measurement point.

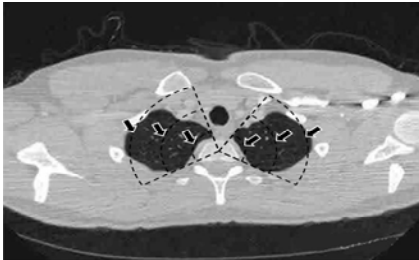


Fig. 1. Measurement points in T2 level

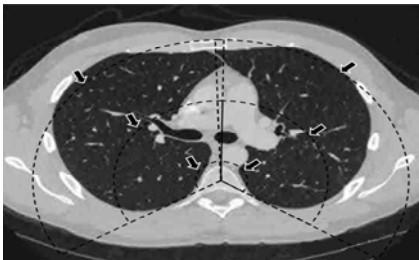


Fig. 2. Measurement points in T6 level

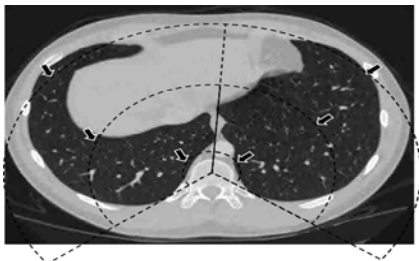


Fig. 3. Measurement points in T11 level

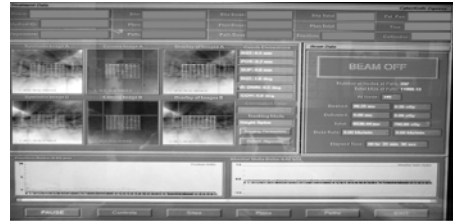


Fig. 4. The console monitor of cyberknife

3. Result

3.1 The range of motion for each positions

The moving distances of 3 axial directions for each point on total of 28 patients are shown from Fig. 5 to 7. Also, The average moving distance and standard deviation for each axial direction per each point is shown from Table 2.

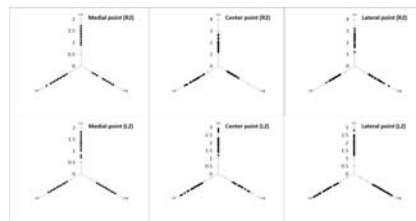


Fig. 5. Result of motion on T2 level

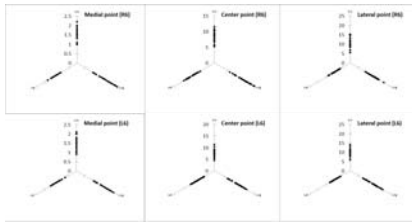


Fig. 6. Result of motion on T6 level

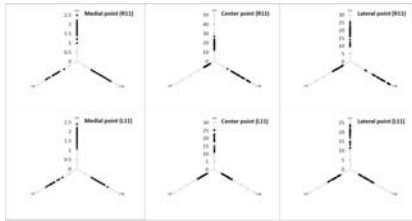


Fig. 7. Result of motion on T11 level

Table 2. The data in column Mean value and Standard deviation of motion length[mm]

			Vertical	Longitudinal	Lateral
Right Lung	T2	Med.	1.3±0.25	1.2±0.27	1.1±0.23
		Cnt.	1.9±0.46	1.4±0.32	2.3±0.48
		Lat.	2.3±0.48	2.3±0.48	2.0±0.34
	T6	Med.	1.5±0.31	1.8±0.43	1.4±0.21
		Cnt.	8.3±1.68	11.3±2.39	8.5±1.63
		Lat.	10.7±2.48	14.2±2.72	9.8±2.05
	T11	Med.	1.7±0.35	1.4±0.34	1.4±0.3
		Cnt.	18.5±4.03	32.1±7.32	8.8±2.27
		Lat.	18.2±3.92	22.2±4.79	9.1±2.11
Left Lung	T2	Med.	1.4±0.30	1.2±0.24	1.2±0.28
		Cnt.	2.0±0.42	1.6±0.28	1.9±0.43
		Lat.	1.9±0.43	2.0±0.38	2.1±0.48
	T6	Med.	1.5±0.35	1.7±0.35	1.2±0.24
		Cnt.	7.7±1.55	11.3±2.53	8.5±1.85
		Lat.	10.0±2.15	14.3±3.29	9.5±1.72
	T11	Med.	1.7±0.33	1.4±0.26	1.4±0.26
		Cnt.	18.5±4.17	9.5±2.19	9.0±1.88
		Lat.	18.3±3.56	9.8±2.43	9.3±2.00

At the T2 level, only the left, right, and right lungs were observed within 3 mm from the medial, medial, and lateral sides. In the case of T6 level, only the motion within 2 mm from the inner side was observed but the middle was from 7 mm to 12 mm, unlike the T2 level. In the case of the outer side, the movement was from 9 mm

to 15 mm, and the difference between the left and right was within the error range. In the case of T11 level, we could observe the movement within 2 mm of the medial side and the large movement from 8 to 33 mm in the medial side. In the case of the outer side, the movement from 9 mm to 23 mm was observed, and it was confirmed that the range of movement was narrower than the intermediate position. And the right side showed a higher range than the left side. This is judged by the effect of the heart.

3.2 Assessment of PDV

The PDV for each node on the Cyberknife therapy is as in Fig. 8, and the range of PDV measuring the moving distance according to each position and direction, and the result of comparison are shown in Fig. 9.

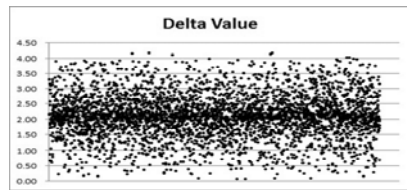


Fig. 8. The graph of PDV

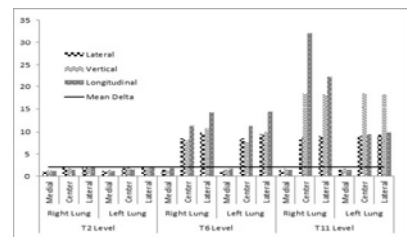


Fig. 9. The graph of measurement value and mean PDV

In the case of PDV, the actual clinical results show that the tolerance of motion within a maximum of 4.5 mm is acceptable. Therefore, the motion of each position was set to an error limit of 4.5 millimeters. As a result, the validity of the synchrony technique could not be guaranteed for

all the T2 levels. The T6 and T11 levels were within the error range only from the inside.

4. Discussion

The Cyberknife therapeutic apparatus for stereotactic radiotherapy uses the synchrony technique on the pulmonary tumor. However, for the tumors near the vertebrae, there is no standard provided for selection between the vertebral tracking technique and the synchrony technique, so the change in the lung tissue according to the distance from the vertebrae is evaluated to provide the standard for selecting the therapeutic technique. The upper, middle and lower parts of the lung were divided into left and right, and the movement of the lung tissue was compared on the short, medium and long distances from the vertebrae. The comparison results showed that the points included within the posture error value of PDV during the therapy were only the short distance from the vertebrae for both left and right sides in case of total upper part of the lungs and the middle and lower parts. Also, other points showed very high values than the PDV. The movement of the tissues according to each position was evaluated to provide the standard for selecting the therapeutic technique according to the position of the pulmonary tumor. However, the evaluation positions are very limited, and there may be concerns of having difference for each subject due to the different shapes and functions of the lungs on selecting the position. Therefore, to set the standard on the position of the lungs, classification should be enabled according to the positions and functions of the pulmonary tumors, and the measurement points on the middle and lower parts should be segmentalized more in detail based on the results of this study to be evaluated. This study suggests that it is possible to utilize the existing treatment method as a

basic data to improve the ineffective treatment and to reduce the burden on the patient and the operator and to aim for efficient treatment. In addition, the stability, respiration pattern and stability of patients should be considered in further studies to provide more reliable and detailed standard. Most of the cyber knife treatments for pulmonary tumors used in clinical practice are usually applied with synchrony technique. Therefore, although the data to be compared with the experimental results are insufficient, future studies will examine reliability through continuous data collection.

5. Conclusion

As a result of applying the average moving distance for each measurement point with 2.1 mm as the error value of the patient of PDV on the Cyberknife therapy to 28 patients in this study, all measurement points in the No. 2 thoracic vertebrae height were within the PDV value, and in the No. 6 thoracic vertebrae and No. 11 thoracic vertebrae heights, only the measurement points close to the vertebrae were shown to be within the PDV value. Also, other points showed very high values than the PDV value. As for the synchrony technique, the exposure amount is higher than that of the vertebral tracking technique in CT simulation, and long preparation and therapy time are required on the cyberknife therapy. Therefore, in the case of radiotherapy of pulmonary tumor by using the Cyberknife, the apex of the lung should use the Vertebral tracking technique, and the middle and lower parts of the lung should use the vertebral tracking technique only when the point is within 5 mm range from the closest point from the center of the vertebrae. For other points, the synchrony technique should be used for therapy.

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