Analysis of the Dose Distribution of Moving Organ using a Moving Phantom System

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Purpose: Few researches have been performed on the dose distribution of the moving organ for radiotherapy so far. In order to simulate the organ motion caused by respiratory function, multipurpose phantom and moving device was used and dosimetric measurements for dose distribution of the moving organs were conducted in this study. The purpose of our study was to evaluate how dose distributions are changed due to respiratory motion.
Materials and Methods: A multipurpose phantom and a moving device were developed for the measurement of the dose distribution of the moving organ due to respiratory function. Acryl chosen design of the phantom was considered the most obvious choice for phantom material. For construction of the phantom, we used acryl and cork with density of 1.14 g/cm^3, 0.32 g/cm^3 respectively. Acryl and cork slab in the phantom were used to simulate the normal organ and lung respectively. The moving phantom system was composed of moving device, moving control system, and acryl and cork phantom. Gafchromic film and EDR2 film were used to measure dose ditrbutions. The moving device system may be driven by two directional step motors and able to perform 2 dimensional movements (x, z axis), but only 1 dimensional movement (z axis) was used for this study.
Results: Larger penumbra was shown in the cork phantom than in the acryl phantom. The dose profile and isodose curve of Gafchromic EBT film were not uniform since the film has small optical density responding to the dose. As the organ motion was increased, the blurrings in penumbra, flatness, and symmetry were increased. Most of measurements of dose distrbutions, Gafchromic EBT film has poor flatness and symmetry than EDR2 film, but both penumbra distributions were more or less comparable.
Conclusion: The Gafchromic EBT film is more useful as it does not need development and more radiation dose could be exposed than EDR2 film without losing film characteristics. But as response of the optical density of Gafchromic EBT film to dose is low, beam profiles have more fluctuation at Gafchromic EBT. If the multipurpose phantom and moving device are used for treatment Q.A, and its corrections are made, treatment quality should be improved for the moving organs.

Key words: multipurpose phantom, moving device, gafchromic EBT film, EDR2 film

INTRODUCTION

In the thoracoabdominal regions, lung, liver, and abdominal organs are moved due to breathing.[1,2] It influence accuracy of image acquisition, treatment planning, and dose distribution.[3] If the respiratory motion dose not take into account during image aquisition when conventional radiotherapy and 3-dimensional conformal therapy are applied in thoracic and abdominal region, the difference can occur in the dose distribution of Planning Target Volume (PTV) and OAR (Organ at risk) that are generated by RTP and measurement.[4] For that reason conventional radiotherapy needs to increase the margin of the clinical target volume (CTV) when the PTV of moving organ was defined.[5] Radiation delivery in the presence of intrafraction organ motion causes a blurring of dose distribution if it dose not correct the organ motion.[6]

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This displacement results in an deviation between the intended dose and the dose actually delivered. The custom made multipurpose phantom[7,8] was used for dosimetric measurements during respiratory motion. The purpose of this study was to evaluate how dose distributions are changed due to respiratory motion.

METHODS AND MATERIALS

Multipurpose phantom system was performed using 6 MV photon beam from a linear accelerator (21EX, Varian, USA)(Fig. 1). To analyze the dose distribution, the films were exposed inside the phantom with initial setup condition of field size 5×5 cm^2, 100 cm source axis distance (SAD) and 5 cm depth.

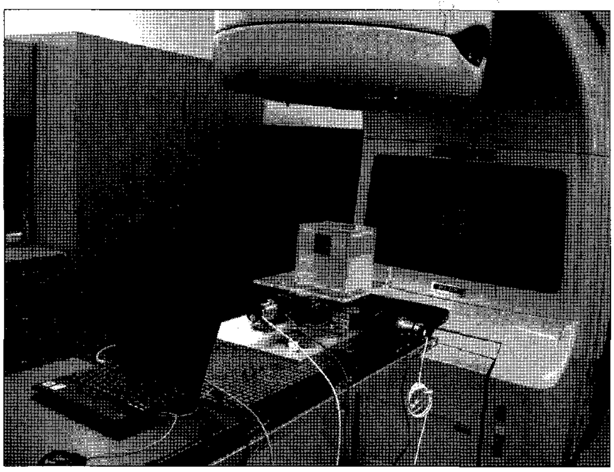

Fig. 1. The MPP (multipurpose phantom) and moving devide setup on the couch of 21EX Linear accelerator (Varian, USA).

1. Design of a Multipurpose Phantom (MPP)

The phantom was designed and fabricated for TLD, film, ionization chamber dosimetry. Multipurpose phantom consists of three parts of slabs; first slabs are to change beam direction, second ones to simulate the organ (lung, air cavity, normal organ), third ones to place the dosimeters (TLD, ionization chamber, film)(Fig. 2). Acryl was considered the most proper choice for phantom material. For construction of the phantom, acryl with density of 1.14 g/cm^3 was used. Acryl and cork slab in the phantom were used to simulate the normal tissue and lung respectively.

2. Simulation of Organ Motion and Beam Delivery

In order to simulate the organ motion caused by respiratory motion, a moving phantom system was designed and fabricated. The moving phantom system was composed of moving device, moving control system, and multi purpose phantom. The moving device system (Parker, USA) may be driven by two directional step motors and able to perform 2 dimensional movements (x, z axis), but only 1 dimensional movement (z axis) was used for this study. The control system was consisted

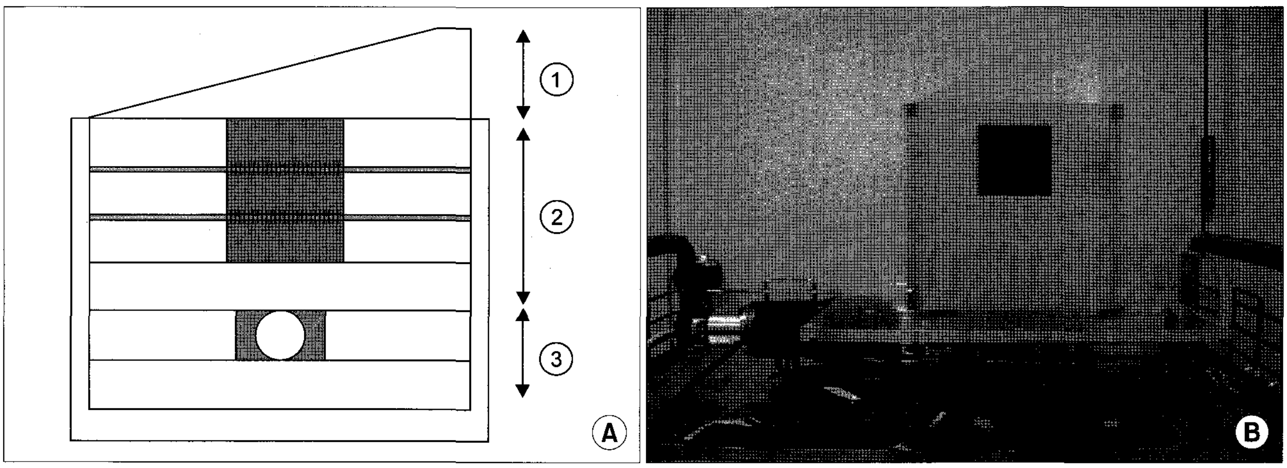

Fig. 2. (A) Schematic illustration of a multipurpose phantom for dosimetry. The first slabs (①) are to change beam direction, second ones (②) to simulate the moving organ (lung, air cavity, normal organ) and to insert the film, and third ones (③) to set the dosimeter (TLD, Ionization chamber). (B) Photo of a multipurpose phantom set on the moving device with 1 step motor.

of a laptop notebook and a dedicated software.

The films were inserted into the 5 cm depth, SSD 100 cm, field size 10×10 cm^2, and 6 MV energy. Radiation doses were delivered under two conditions; 1) static condition, 2) moving condition. For the film dosimetry, EDR2 film (Kodak, USA) and Gafchromic EBT film (ISP, Wayne) were used.[9,10] EDR2 film has an extended dose range of about 600 cGy without saturation.

The Gafchromic EBT film has higher dose range than EDR2 film. Although a Ghfchromic EBT film has fluctuations in optical density response to the dose, it has a lot of advantages such as an extended dose range of approximately 1∼800 cGy, a near tissue equivalent, no energy dependence, faster and lower post-exposure density growth, and an insensitivity to room light. The most unique characteristic dose not require film processing. The moving ranges for the phantom are 1 cm, 1.5 cm, and 2 cm since lung move along superior-inferior direction about 1∼2 cm by respiration. The films are irradiated in the cork and acryl phantoms. The EDR2 films are irradiated in the cork phantom to compare to the Gafchromic film. The irradiated films were analyzed by the Vidar scanner (Vidar, USA).

RESULTS

1. Construction of Multipurpose Phantom

The multipurpose phantom was constructed with the aim of being easily used for film, TLD, and ionization chamber dosimetry. Economical as well as practical concerns were considered in the phantom design and acryl and cork material were chosen as the main body of phantom. Acryl phantom was often used as solid water substitutes in radiotherapy

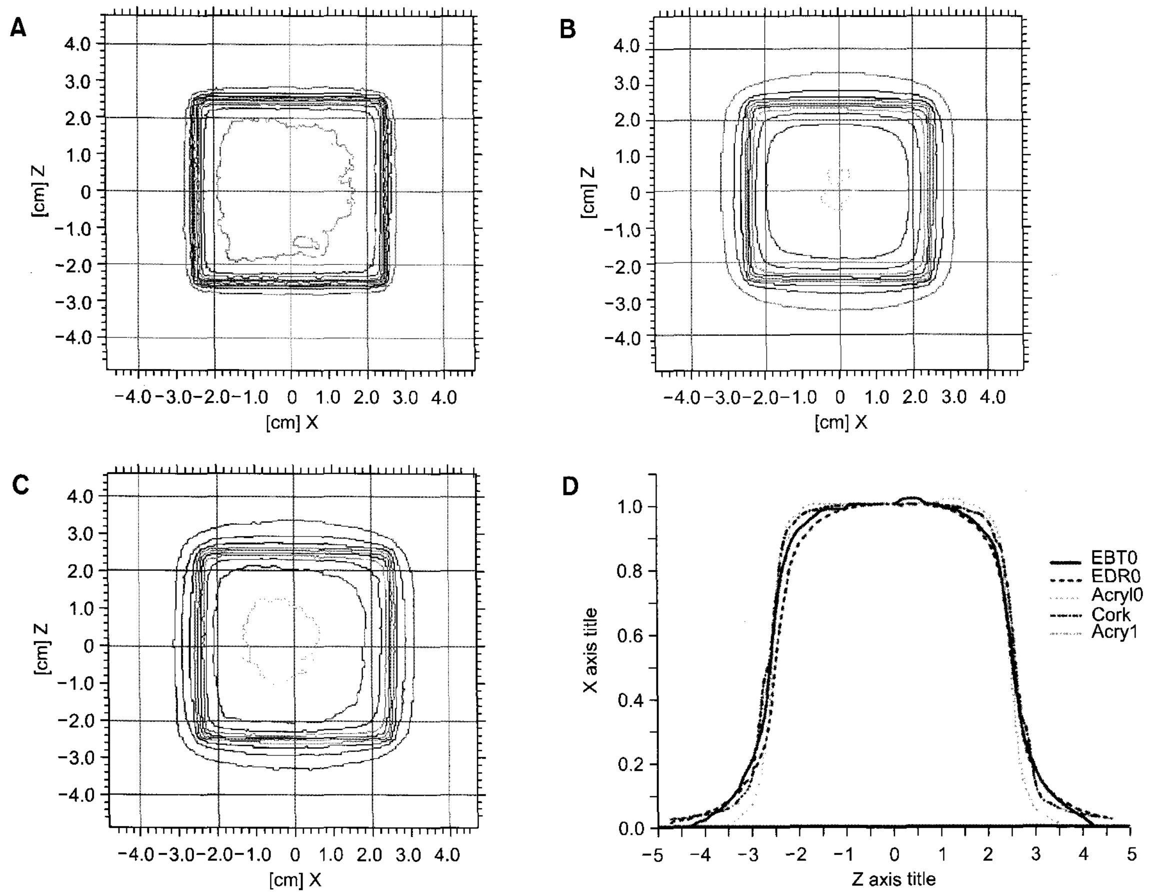

Fig. 3. The dose distribution of (A) the Gafchromic EBT film in acryl phantom, (B) the EDR2 film in cork phantom, and (C) the Gafchromic EBT film in cork phantom. (D) The comparison of the Z-axis beam profiles and the plan profiles of cork and acryl phantom.

which was easy to setup, available anywhere, and reasonable in price. The first slab part with wedge-like angle in the phantom was used to measure the transmission rate of the beam at posterior oblique direction. It was designed to correct dosimetrically irregular patient body. The second slab part was used to simulate organ material with similar density. Acryl part was used as a substitute to normal organ. Cork part was used as a substitute to lung. The dosimetric measure-

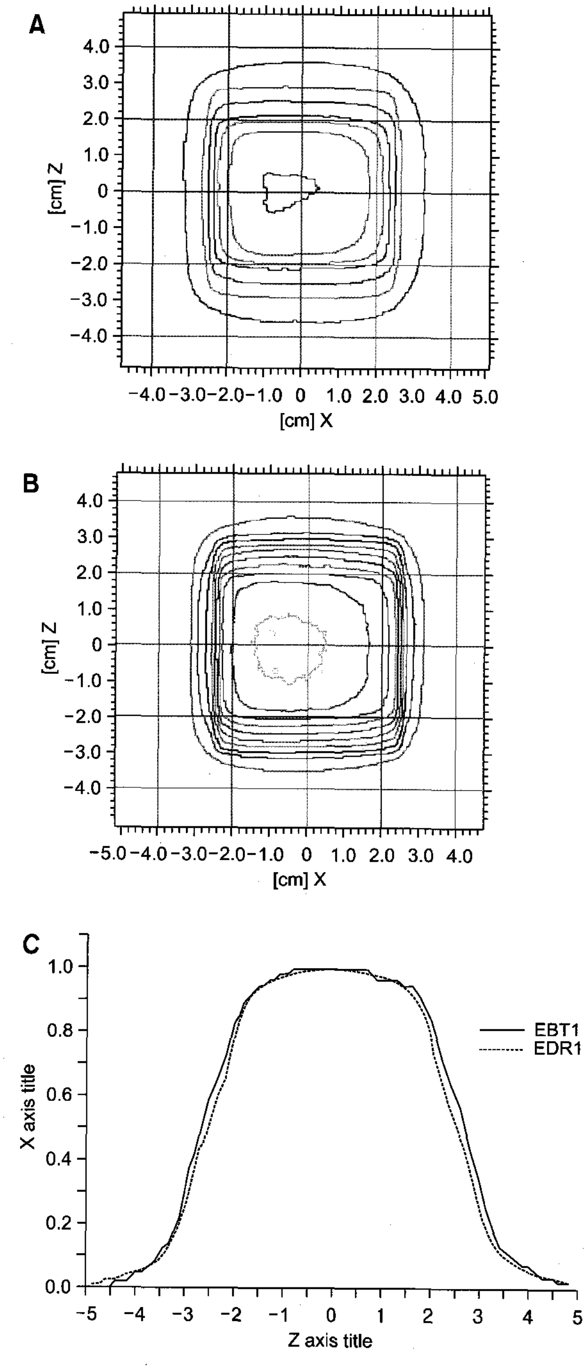

Fig. 4. The comparison of the dose distribution from (A) EDR2 film and (B) Gafchromic EBT film when the phantom moved back and forth by 1 cm with cork phantom. (C) The dose profile of Gafchromic and EDR2 film.

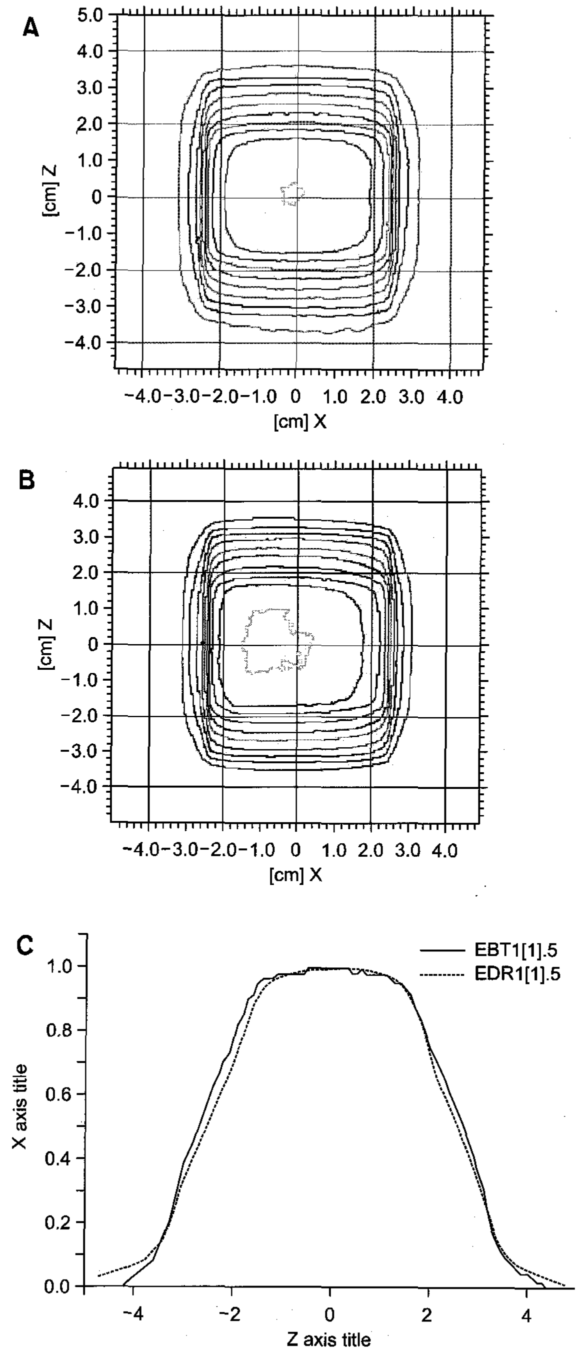

Fig. 5. The comparison of the dose distribution from (A) EDR2 film and (B) Gafchromic EBT film when the phantom moved back and forth by 1.5 cm with cork phantom. (C) The dose profile of Gafchromic and EDR2 film.

ments were performed in a multipurpose phantom on position and depth of the moving organ during respiratory motion by moving device. In the third slab part, dosimeter holes were made to allow the measurements using ionization chamber and TLD.

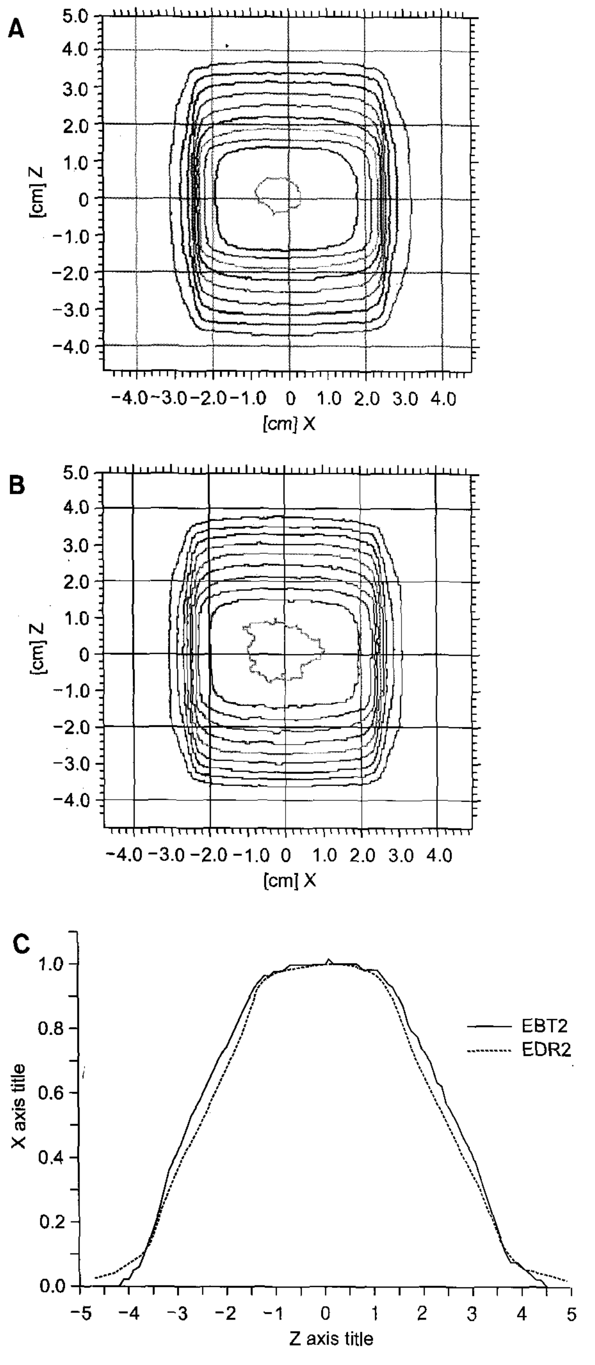

Fig. 6. The comparison of the dose distribution from (A) EDR2 film and (B) Gafchromic EBT film when the phantom moved back and forth by 2 cm with cork phantom. (C) The dose profile of Gafchromic and EDR2 film.

2. Simulation of Organ Motion and Beam Delivery

In order to simulate the organ motion caused by respiratory motion, dynamic phantom system was designed and fabricated. The moving phantom system was composed of moving device, moving control system, and phantom system. The moving device was driven by two step motors and able to perform 2 dimensional movements with x, z axis. The control system was consisted of a laptop notebook and a dedicated software. The moving phantom was controlled to move in one direction (z axis) for this study.

As the organ motion was increased, the blurring in penumbra, flatness, and symmetry were increased(Fig. 3, 4, 5, 6). So if the moving organ was irradiated, it was considered the change of dose distribution. It is noted from the film that larger penumbra was shown in cork phantom than in the acryl phantom (Fig. 3). The dose profile and isodose curve from Gafchromic EBT film are not shown uniform since it has low response of optical density to the dose. However it has simple handling. As the organ motion was increased, the blurring in the dose distribution was increased (Fig. 4, 5, 6). For all the measurements of dose distributions, Gafchromic EBT film has poor flatness and symmetry than EDR2 film, but both penumbra distributions were more or less comparable (Table 1).

Table 1. The penumbra, flatness and symmetry under various conditions (Unit: mm)

Phantom	Film	Moving	Penumbra	Flatness	Symmetry
Acryl	Gaf EBT	Not	0.33	1.5	0.1
Cork	Gaf EBT	Not	0.66	5.4	1.9
Cork	EDR2	Not	0.64	4.5	0.5
Cork	Plan	Not	0.56	3.4	0.2
Acryl	Plan	Not	0.56	3.5	0.1
Cork	EDR2	1 cm	1.11	14.2	1.4
Cork	Gaf EBT	1 cm	1.11	15.4	3.9
Cork	EDR2	1.5 cm	1.66	18.6	2.0
Cork	Gaf EBT	1.5 cm	1.46	17.3	3.7
Cork	EDR2	2 cm	1.91	20.8	1.5
Cork	Gaf EBT	2 cm	1.78	24.2	4.2

DISCUSSION AND CONCLUSION

First of all, if the moving organ was irradiated, it was considered the change of dose distribution. The treatment planning and irradiation of moving organ was done after the deviation of movement was measured.

The Gafhromic EBT film is more useful as it does not need development and more radiation dose could be exposed than EDR2 film without losing film characteristics. But as the response of the optical density of Gafchromic EBT film to dose is low, beam profiles have more fluctuation at Gafchromic EBT. In near future, with the improvement of the control software in the moving device and the precise information on the organ motion using image modality such as fluoroscopy, and CT simulator, more accurate evaluation of dose distributions will be performed. If the multipurpose phantom and moving device are used for treatment Q.A, and its corrections are made, treatment quality should be improved for the moving organs.

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Abstract

구동팬텀 시스템에 의한 움직이는 장기의 선량분포 분석

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김연래 · 박병문 · 배용기 · 강민영 · 이귀원[1] · 방동완

목 적: 움직이는 장기의 방사선치료시에 움직임을 고려한 선량분포의 연구가 많이 이루어지지 않았고, 정적인 상태로서의 선량분포가 고려된 치료 및 연구가 이루어졌다. 그래서 본 연구는 구동팬텀 시스템을 이용하여 움직이는 장기의 선량분포 계측을 시행하였다. 이 연구의 목적은 호흡에 따른 선량분포의 변화가 어떻게 일어나는지에 대한 실험적 계측에 대한 평가이다.

재료 및 방법: 호흡에 의한 움직이는 장기의 선량분포 측정을 위해서 다목적 팬텀과 구동팬텀을 고안 하였다. 다목적 팬텀의 구성은 아크릴과 코르크를 사용하였고, 아크릴의 밀도는 1.14 g/cm^{3}이고 코르크는 0.32 g/cm^{3}이다. 아크릴은 정상조직을 표현하기 위해 사용되었고, 코르크는 폐를 묘사하기 위해 제작 되었다. 측정용 필름은 가프크로믹 필름과 EDR2 필름을 사용하였다. 구동팬텀 시스템은 상하좌우 2차원적인 움직임을 하도록 설계되었으나 본 실험은 1차원적인 움직임만으로 구동하여 측정하였다.

결 과: 코르크 팬텀에서 측정된 선량분포가 아크릴에서 측정된 선량분포보다 반음영이 크게 나타났다. 가프크로믹 필름으로 측정된 선량분포는 선량분포에 따른 광학농도가 낮기 때문에 분포곡선이 평탄하지 않았다. 내부장기의 움직임이 증가함에 따라 선량분포에서 반음영, 평탄도, 대칭도가 점점 증가하였다. 모든 가프크로믹 필름으로 측정된 선량분포는 EDR2 필름으로 측정된 필름보다 평탄도나 대칭도가 좋지 않았지만 반음영은 비슷하게 분포되었다.

결 론: 가프크로믹 필름은 현상이 필요 없기 때문에 사용하기 편하고, 조그만 크기로도 쉽게 잘라서 사용할 수 있다. 또한 많은 양의 방사선을 조사할 수 있는 장점이 있다. 그러나 선량에 따른 광학농도의 변화가 작기 때문에 측정 시에 선량분포에 평탄도가 좋지 않다. 움직이는 장기의 방사선치료시 다목적 팬텀과 구동팬텀을 이용하여 질보정이 이루어진다면 치료효과를 향상시킬 것이라 사료된다.

핵심용어: 다목적 팬텀, 구동장치, 가프크로믹 필름, EDR2 필름