# Development of Respiratory Motion Reduction Device System (RMRDs) for Radiotherapy in Moving Tumor: Construction of RMRDs and Patient Setup Verification Program

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## ABSTRACT

The purpose is to develop a system to reduce the organ movement from the respiration during the 3DCRT or IMRT. This research reports the experience of utilizing personally developed system for mobile tumors. The patients clinical database was structured for 10 mobile tumors and patient setup error measurement and immobilization device effects were investigated. The RMRD system is composed of the respiratory motion reduction device utilized in prone position and abdominal strip device(ASD) utilized in the supine position, and the analysis program, which enables the analysis on patients setup reproducibility. Dose to normal tissue between patients with RMRDs and without RMRDs was analyzed by comparing the normal tissue volume, field margins and dose volume histogram(DVH) using fluoroscopy and CT images. And, reproducibility of patients setup verify by utilization of digital images. When patients breathed freely, average movement of diaphragm was 1.2 cm in prone position in contrast to 1.6 cm in supine position. In prone position, difference in diaphragm movement with and without RMRDs was 0.5 cm and 1.2 cm, respectively, showing that PTV margins could be reduced to as much as 0.7 cm. With RMRDs, volume of the irradiated normal tissue (lung, liver) reduced up to 20 % in DVH analysis. Also by obtaining the digital image, reproducibility of patients setup verify by visualization using the real-time image acquisition, leading to practical utilization of our software. Internal organ motion due to breathing can be reduced using RMRDs, which is simple and easy to use in clinical setting. It can reduce the organ motion-related PTV margin, thereby decrease volume of the irradiated normal tissue.

**Keywords**: respiratory motion reduction device (RMRD), abdominal strip device (ASD), dose volume histogram (DVH), breathing movement, mobile tumor

## 1. INTRODUCTION

The purpose of radiotherapy is to improve local tumor control without any increase in toxicity. In applying radiotherapy to a moving organ, it is important minimize the movement of the tumor as well as to know precisely where the tumor is. This will increase the amount of radiation and toxicity to the normal tissues (1, 2). In this regard, 3-dimensional conformal radiotherapy (3DCRT) or intensity-modulated radiotherapy (IMRT) is used along with a respiration gated radiotherapy (RGRT) method (3, 4). There have been many studies on the efficacy of the RGRT method. However, 3DCRT has not been reported to appropriately reflect the tumor movement under the influence of respiration. In RGRT, respiration control enables the effective delivery of the maximum dose to the tumor as well as minimizing the irradiation of normal tissue (5-7). According to the ICRU Report 50, the planning target volume (PTV) is a geometrical concept. This definition is used to select the appropriate beam sizes and beam arrangements, taking into consideration the net effect of all possible geometrical variations. This is done in order to ensure that the prescribed dose is actually absorbed in the clinical target volume (CTV) (8). The PTV margin is an important element in radiotherapy. However, geometric errors frequently occur. By analyzing organ movement using fluoroscopy, diaphragm movement ranges from 10 to 30 mm in an up and down movement. The PTV for tumors in the abdomen or thorax includes enough margins for breathing-related movement of the tumor volumes during treatment. Depending on the location of the tumor, the magnitude of the PTV margin extends from 10 mm to 30 mm, which substantially increases the volume of normal tissue irradiated. Therefore, this results in an increasing normal tissue complication probability (NTCP) (9, 10). Consequently, it is essential to minimize the dose to the normal tissue by reducing the extra portion covering the movement of the organs according to the respiration. This eventually creates dosimetric and geometric uncertainties. In this study, a respiratory motion reduction device (RMRDs) was developed and tested to reduce PTV margins in patients with moving tumor cancer breathing-related a simple and handy method.

## 2. MATERIALS AND METHODS

### 2-1. Construction of the respiratory motion reduction device (RMRDs)

The RMRD was designed to minimize respiration movement of the patient during radiotherapy. The styrofoam ($200\times100\times100$ $mm^3$) was designed to press down on the upper abdomen in an appropriate size considering the anatomy of the patient. MeV-Green ($400\times400$ $mm^2$) was used to fix the abdomen in place while the acryl rods ($400\times10\times10$ $mm^3$) and a board ($500\times800\times100$ $mm^3$) were used to enhance the reproducibility of the patients position and the stability. In addition a belt-fixing device(abdomen strip device, ASD) was used to minimize bodily movement.

### 2-2. Measurement of organ movement using fluoroscope image

The simulator (Ximatron™, Varian Medical Systems, Palo Alto, CA), CT-Simulator (PQ 5000, Marconi, Ohio) and radiation treatment planning (RTP) software (AcQ-Plan, Marconi, Ohio) were used in this hospital. During simulation, the diaphragm movements from 10 moving tumor patients, which were considered to be the cause of internal organs movement, were observed with a fluoroscope. To collect the image, the results according to the RMRD position were analyzed. The movement in the supine and the prone position were also analyzed to determine the differences according to the position.

### 2-3. Measurement of organ movement using computerized tomography image

Organ movement during both regular and maximum respiration was analyzed in three patients. The image collection was accomplished by analyzing the digitally reconstructed radiography (DRR) image redesigned from the computerized tomography image. Sixty-six images were obtained with a gap of 3 mm, 27.5 cm area of interest, and a 0.43mm pixel size. In each case, the movement of the tumor center-of-gravity and the internal organ movement were analyzed according to distance and angle by overlapping the computerized tomography images. The analysis was done using fusing software for various images, and the following equation was used to measure the total displacement (11).

### 2-4. Analysis of the dose-volume histogram (DVH)

In each case, the extra portion of the planning target volume was considered by measuring the organ movement through respiration. The radiation treatment plan was determined for 10 moving tumor cancer patients using the AcQ-Plan. The PTV was ascertained by volume including the margin, which considered the degree of organ movement according to the error in the patient's position and respiration in the GTV. The treatment plan was established to minimize the planning volume in a normal liver. In addition the DVH of a normal liver was analyzed in particular, the volume of the normal liver where 50% of the prescribed dose is delivered.

## 3. RESULTS

### 3-1. Measurement of organ movement using fluoroscope image

The movement distance of the diaphragm was 16±1.9 mm in the supine position and 12±1.9 mm in the prone position, i.e. the distance of the prone position was 4 mm smaller than that of the supine position. In case where the RMRD produced by our hospital was used, the movement distance of the diaphragm was only 5±1.4 mm, which means that the organ movement can be reduced, and when the belt was used, there was an additional reduction of 3±0.9 ㎜.

### 3-2. Measurement of organ movement using computerized tomography image

The patients breathed regularly, and a computerized tomography image during maximum breathing was obtained and overlapped in order to analyze the movement of the internal organs both in distance and angle, such as the movement of the center of the tumor, left and right kidney, normal liver etc. There was a horizontal movement of 2.2～4.0 mm. The movement from the front to the back was 1.3～12.4 mm, the vertical movement for the center point of planning area was 15.5～26.2 mm. The horizontal movement was 1.2～1.7 mm and the front to back movement was 1.4～6.0 mm. The vertical movement of the left kidney was 7.0～17.0 mm, the horizontal movement was 1.2～4.9 mm, and the front to back movement was 2.1～7.0 mm. The vertical movement of the right kidney was 14.0～24.3 mm. The total displacement was 18.7～26.5 mm for the tumor, 7.2～18.1 mm for the left kidney and 14.5～25.8 mm for the right kidney. By verifying the movement distance of the diaphragm using the fluoroscopic images from the organ movement measurements, and the computerized tomography image, the movement of the actual organ could be observed .

### 3-3. Analysis of the dose-volume histogram (DVH)

The volume of the normal liver, where 50% of the prescribed dose volume was analyzed from the total liver volume in the DHV was 41% in the supine position and 40% in the prone position in the case where the RMRD was not used. In the case where the RMRD was used, the figure was 30.7% for the prone position. When the belt device was also used, the figure was 21%, demonstrating that the volume of the normal liver irradiated had a maximum decrease of 20%.

## 4. DISCUSSION AND CONCLUSION

In the radiotherapy of moving organs due to respiration such as the liver and lungs, the volume of the treatment plan must include the movement of the tumor due to respiration. In this case, the planned volume increases, which results in increased toxicity. Therefore, efforts to minimize the PTV by minimizing the respiration-related tumor movement are essential. There have been many studies on respiration control radiotherapy. Wong et al (12) attempted to prevent organ movement through respiration by artificially controlling respiration. This study is under active investigation because three-dimensional conformal radiation therapy is not effective in reflecting tumor movement during radiotherapy. However, respiration control radiotherapy minimizes tumor movement by controlling respiration thereby reducing the unnecessary extra portion of the radiation plan area. This can overcome the existing limitation of radiotherapy due to toxicity in the surrounding normal tissues. However, the ABC (active breathing control) product currently used in respiration control radiotherapy requires an artificial control of respiration. The ABC has a weak point in that the expensive treatment device that is connected to the main operation device must be purchased separately. Furthermore, it is limited to a certain product. This increases the rate of the breakdown, which is not appropriate in the facilities treating many patients due to the increase in the treating period. Therefore, in developing an advanced radiotherapy method that compensates for the movement of the area to be treated through respiration, developing a broadly applicable system, which can be utilized in currently used radiation treatment devices, is essential. In this study, a method that minimized the error due to the internal organ movement was investigated. As a result of analyzing the volume of the normal liver where 50% of the treated volume was planned by applying it in the PTV in the treatment plan, the volume planned in the normal liver was reduced to a maximum of 20%. Therefore, the PTV caused by the organ movement through respiration was reduced. This device also appeared to the effective in terms of simplicity, accuracy and reproducibility. Furthermore, to determine the artificial anatomic changes, which can occur using the RMRD, computerized tomography images were collected from the horizontal, vertical, front, and rear direction. According to the analysis, it was shown that there were no anatomical changes, which verified the effectiveness of the RMRD.

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