Development of Respiratory Motion Reduction Device System (RMRDs) for Radiotherapy in Moving Tumors

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Background: The internal target volume (ITV) for tumors in the abdomen or thorax includes sufficient margin for breathing-related movement of tumor volumes during treatment. Depending on the location of the tumor, the magnitude of the ITV margin extends from 1 to 3 cm, which increases substantially the volume of the irradiated normal tissue, hence resulting in an increase in normal tissue complication probability (NTCP). We developed a simple and handy method which can reduce ITV margins in patients with moving tumors: the respiratory motion reduction device system (RMRDs).

Methods: The patient’s clinical database was structured for moving tumor patients and patient set-up error measurement and immobilization device effects were investigated. The system is composed of the respiration presser device (RPD) utilized in the prone position and the abdominal strip device (ASD) utilized in the supine position, and the analysis program, which enables analysis of patient set-up reproducibility. It was tested for analyzing the diaphragm movement from patients with RMRDs, the magnitude of the ITV margin was determined and the dose–volume histogram (DVH) was computed using treatment planning software. The dose to normal tissue in patients with and without RMRDs was analyzed by comparing the fraction of the normal liver receiving 50% of the isocenter dose.

Results: Average diaphragm movement due to respiration was 16 ± 1.9 mm in the case of the supine position, and 12 ± 1.9 mm in the case of the prone position. When utilizing the RMRDs, which was personally developed in our hospital, the value was reduced to 5 ± 1.4 mm, and in the case in which the belt immobilization device was utilized, the value was reduced to 3 ± 0.9 mm. In the case where the strip device was utilized, the value was proven to reduce to 4 ± 0.3 mm. As a result of analyzing the volume of normal liver where 50% of the prescription dose is irradiated in DVH according to the radiation treatment planning, the use of the RMRD can create a reduction of 30% to the maximum. Also by obtaining the digital image, the function of comparison between the standard image, automated external contour subtraction, etc. was utilized to develop a patient set-up reproducibility analysis program that can evaluate the change in patient set-up.

Conclusion: Internal organ motion due to breathing can be reduced using RMRDs, which is simple and easy to use in the clinical setting. It can reduce the organ motion-related planning target volume margin, thereby decreasing the volume of irradiated normal tissue.

Key words: respiratory motion reduction device system (RMRDs) – moving tumor – dose–volume histogram (DVH) – breathing movement – set-up reproducibility

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 to minimize the movement of the tumor, as well as to locate it precisely, in order not to increase the amount of radiation and toxicity to the normal tissues (1,2). In this regard, three-dimensional conformal radiotherapy (3DCRT) or intensity-modulated radiotherapy (IMRT) is now widely used along with a respiration gated radiotherapy (RGRT) method (3,4). There have been many studies on the efficacy of the RGRT method. However, there have been few reports on 3DCRT, which was devised to appropriately reflect
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 ICRU Report 62, the internal target volume (ITV) is defined as the sum of the clinical target volume (CTV) and the internal margin (IM). This definition is used to select the appropriate beam sizes and beam arrangements, taking into consideration the net effect of all possible geometric variations (8). The ITV 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 ITV for tumors in the abdomen or thorax includes sufficient margins for breathing-related movement of the tumor volumes during treatment. Depending on the location of the tumor, the magnitude of the ITV margin extends from 10 to 30 mm, which substantially increases the volume of normal tissue irradiated (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 due to respiration, as this eventually creates dosimetric and geometric uncertainties.

In this study, a respiratory motion reduction device system (RMRDs) was developed and tested to reduce ITV margins in patients with liver cancer, providing a simple and handy method.

**MATERIALS AND METHODS**

**CONSTRUCTION OF THE RMRDS**

The RMRD was designed to minimize respiration movement of the patient during radiotherapy. The system is composed of the respiration presser device (RPD) utilized in the prone position and the abdominal strip device (ASD) utilized in the supine position. The styrofoam (200 × 100 × 100 mm³) was designed to press down on the upper abdomen in an appropriate size considering the anatomy of the patient. MeV-Green (immobilization device, Chunsung Co., Korea, 400 × 400 mm²) was used to fix the abdomen in place while the acryl rods (400 × 10 × 10 mm³) and a board (500 × 1000 × 100 mm³) were used to enhance the reproducibility of the patient’s position and the stability. In addition, a belt-fixing device was used to minimize bodily movement (Figs 1–3).

**MEASUREMENT OF ORGAN MOVEMENT USING FLUOROSCOPE IMAGE**

The simulator (Ximatron™, Varian Medical Systems, Palo Alto, CA), CT-Simulator (PQ 5000, Marconi, OH) and radiation treatment planning software (AcQ-Plan, Marconi, OH) were used in this hospital. During simulation, the diaphragm movements from 10 liver cancer patients (five times per patient during 2 weeks), which were considered to be

![Figure 1](https://academic.oup.com/jjco/article-abstract/34/11/686/828144) Figure 1. Construction of the RMRDs. It was tested for both supine and prone positions with and without the RMRD when patients breathed freely.
the cause of internal organ movement, were observed with a fluoroscope. To collect the image, the results according to the RMRD position were analyzed using the video and custom-made software. The movement in the supine and the prone position was also analyzed to determine the differences according to position.

MEASUREMENT OF ORGAN MOVEMENT USING COMPUTERIZED TOMOGRAPHY IMAGE

Organ movement during both regular and maximum respiration was analyzed in three patients. 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, 275 mm area of interest, and a 0.43 mm pixel size. In each case, the movement of the tumor’s center of gravity and the internal organ movement were analyzed according to the distance and angle by overlapping the computerized tomography images. The analysis was carried out using fusing software for various images, and the following equation was used to measure the total displacement (11):

\[ SD_{\text{total}}^2 = SD_{\text{lat}}^2 + SD_{\text{ap}}^2 + SD_{\text{long}}^2 \]

where \( SD_{\text{total}} \) is the standard deviation of total shift length, \( SD_{\text{lat}} \) is the standard deviation of lateral (right/left) shift length,
$SD_2^2$ is the standard deviation of vertical (anterior/posterior) shift length and $SD_{long}^2$ is the standard deviation of longitudinal (superior/inferior) shift length.

**ANALYSIS OF THE DOSE–VOLUME HISTOGRAM (DVH)**

In each case, the extra portion of the planning target volume (PTV) was considered by measuring the organ movement through respiration. The radiation treatment plan was determined for 10 liver 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 gross tumor volume (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 ($TD_{50}$) is delivered.

**RESULTS**

**MEASUREMENT OF ORGAN MOVEMENT USING FLUOROSCOPE IMAGE**

The movement distance of the diaphragm was $16 \pm 1.9$ mm in the supine position and $12 \pm 1.9$ mm in the prone position, i.e. the distance of the prone position was 4 mm less than that of the supine position. In the case where the RMRD produced by our hospital was used, the movement distance of the diaphragm was only $5 \pm 1.4$ mm, which means that organ movement can be reduced, and when the belt was used, there was an additional reduction of $3 \pm 0.9$ mm (Fig. 4, Table 1).

**Table 1.** Movement of diaphragm with and without RMRD during natural respiration.

<table>
<thead>
<tr>
<th>Patient no.</th>
<th>Supine vs Prone</th>
<th>Without RMRD</th>
<th>With RMRD</th>
<th>With RMRD + Belt</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>15.0 vs 10.0</td>
<td>3.0</td>
<td>3.0</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>17.0 vs 13.0</td>
<td>5.0</td>
<td>4.0</td>
<td></td>
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<tr>
<td>3</td>
<td>13.0 vs 10.0</td>
<td>4.0</td>
<td>3.0</td>
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<tr>
<td>4</td>
<td>16.0 vs 12.0</td>
<td>3.0</td>
<td>2.0</td>
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</tr>
<tr>
<td>5</td>
<td>20.0 vs 16.0</td>
<td>6.0</td>
<td>5.0</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>17.0 vs 13.0</td>
<td>3.0</td>
<td>2.0</td>
<td></td>
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<tr>
<td>7</td>
<td>14.0 vs 10.0</td>
<td>4.0</td>
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<td>17.0 vs 12.0</td>
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</tr>
<tr>
<td>10</td>
<td>15.0 vs 11.0</td>
<td>3.0</td>
<td>2.0</td>
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</tr>
</tbody>
</table>

Average $16 \pm 1.9$ vs $12 \pm 1.9$ $5 \pm 1.4$ $3 \pm 0.9$

**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

![Figure 4](https://academic.oup.com/jjco/article-abstract/34/11/686/828144/11)
vertical movement for the center point of the 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 (Fig. 5, Table 2).

ANALYSIS OF THE 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 43.7% in the supine position and 40% in the prone position in the case where the RMRD was not used. In the case where the RRD 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 normal liver irradiated had a maximum decrease of 22.7% (Fig. 6).

DISCUSSION

In the radiotherapy of organs that move 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 ITV 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 direction is being actively pursued because 3DCRT 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 active breathing control (ABC) 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 breakdown, which is not appropriate in facilities treating many patients due to the increase in the treatment 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 internal organ movement was investigated. As a result of analyzing the volume of the normal liver, where 50% of the prescribed dose (TD50) was delivered with and without the RMRD.

![Figure 6. A representative dose–volume histogram (DVH) of the normal liver where 50% of the prescribed dose (TD50) was delivered with and without the RMRD.](https://example.com/image.png)

However, the active breathing control (ABC) 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 breakdown, which is not appropriate in facilities treating many patients due to the increase in the treatment 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 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 ITV in the treatment plan, the volume planned in the normal liver was reduced to a maximum of 22.7%. Therefore, the ITV caused by the organ movement through respiration was reduced.

This device also appeared to be effective in terms of simplicity, accuracy and reproducibility. Furthermore, to determine the artificial anatomical 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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**References**