Original Article

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The Effect of Breathing Biofeedback on Breathing Reproducibility and Patient's Dose in Respiration-gated Radiotherapy

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We evaluated the effect of two kinds of breathing biofeedback technique such as audio-instruction and audio-visual biofeedback on breathing reproducibility and the CTV coverage during repeated treatment regimes in respiration-gated radiotherapy. In this study, the breathing data of nineteen lung cancer patients acquired from Medical College of Virginia (MCV) during five weeks were used. The dose evaluation algorithm was programmed in MATLAB. In the result, the CTV coverage was decreased as 30.0% due to the breathing irreproducibility for free-breathing. For audio-visual biofeedback, the CTV coverage was improved as 20.0% because patients can learn how control their breathing stably. And the audio-instruction was effective to preserve the breathing reproducibility.

Key Words: Respiration-gated radiotherapy, Breathing reproducibility, Breathing biofeedback technique

INTRODUCTION

The intrafraction motion of tumor is considered as the critical problem in radiotherapy. A previous study shows that the internal motion (IM) for SI (superior-inferior) direction is on average 18.5 mm (9.0～32.0 mm) in lower lobe lung.[1)] To have the tolerance for error, the International Commission on Radiation Units and Measurements (ICRU) recommends various target volumes.[2)] However, these enlarged target volumes can cause a complication in normal tissue around the tumor. Various techniques were introduced to reduce the target volume; among them, respiration-gated radiotherapy (RGRT) is widely used because it is available for a conventional linear accelerator with only simple equipment to acquire respiratory cycles.[3-7)] In RGRT, breathing reproducibility during repeated treatment regimes is a major condition to deliver the prescribed dose on target volume. Therefore, various techniques have been developed to control the respiratory motion[8)] such as the active breathing control (ABC) technique with a breath-hold control system and biofeedback technique.[9)] Tohruet et al.[10)] have presented the effect of ABC technique on the internal motion by CT image. They have showed that the use of the ABC can reduce the tumor motion irrespective of the tumor location. Juliet et al.[11)] have showed that the additional image guidance is needed with ABC technique to non-small-cell lung cancer patients who have the irregular breathing patterns. In other words, the ABC technique is not suitable for lung cancer patients or elder patients who have insufficient ability to control their breathing by artificial controller. On the other hand, the biofeedback technique can relieve patients from suffering as a result of the controller which forces to breathe. Previously, several researches have been performed to evaluate

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the effect of biofeedback technique on improvement of the breathing regularity. Jaewon et al.[12] have performed phantom study to analyze the correlation between breathing regularity and motion blurring artifacts with audio-visual biofeedback on 4D PET images. This study has indicated that biofeedback technique can reduce motion blurring artifacts. Peter et al.[13] have also showed that the audio-visual biofeedback is suitable to optimize the treatment time due to the improvement of the blurring of 4D-CT. Taeho et al.[14] have evaluated the correlation between the breathing reproducibility and the audio-visual biofeedback with 15 healthy persons' data acquired during two weeks with 1 week apart. Previously, similar study has been performed by George R. et al.[8] with lung cancer patients' data. In this study, we have evaluated the effect of breathing biofeedback techniques such as audio-instruction (A) and audio-visual biofeedback (AV) on the breathing reproducibility and the CTV coverage during repeated treatment regimes in RGRT. For this study, we have used 19 lung cancer patients' breathing data from Medical College of Virginia (MCV) acquired during five weeks with 1 week apart.

MATERIALS AND METHODS

1. Patient data

A total of twenty two patients' breathing data sets were acquired from Medical College of Virginia (MCV). Excluding three patients who have incomplete data, nineteen patients' data were used in this study. During five weeks, breathing data set were acquired for each patient at every week, and each breathing data set contained three different breathing patterns: free-breathing (FB, non-guidance), audio-instruction (A), and audio-visual biofeedback (AV). When the first breathing pattern is employed, a patient breathes according to his or her will (FB). Subsequently, a patient starts to breathe according to the instruction of the starting point of inhalation and exhalation by audio (A) for steady respiratory cycle. Finally, while looking at the LCD monitor that is displaying the position of marker represents tumor location, a patient breathes together with audio-instruction (named by audio-visual biofeedback, AV). For all of the three acquisitions, respiratory cycles are recorded for four minutes with 0.03 second intervals. A total of 7200 data sets were acquired including the location of the marker (cm), phase (rad), and time (msec) in MCV. Fig. 1 shows the block diagram of this research.

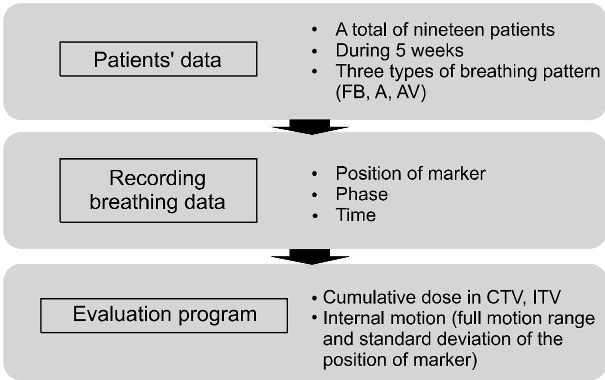

Fig. 1. The block diagram of this research.

2. Evaluation method

In this study, we evaluated the effect of two kinds of breathing biofeedback technique on breathing reproducibility and the CTV coverage. The breathing data at the first week was considered as a respiratory cycle during 4D CT, while the subsequent four weeks' breathing data were considered as respiratory cycles during repeated treatment regimes. Dose calculation programs were programmed with MATLAB for phase gating. In this program, we determined the duty cycle as 20% (40～60%) and the diameter of CTV as 3.0 cm. We defined the internal motion (IM) by two different methods such as the full motion range (the range of the highest and the lowest position) and the standard deviation of the position of marker. Internal target volume (ITV) is defined as the sum of CTV and ±1/2 IM in the SI direction. The developed program delivers a prescribed dose (100 cGy) to ITV, and set the detection point of dose with an interval of 0.1 mm. Cumulative dose at all detection point within ITV over the course of four minutes is assumed as the total dose in ITV. In this study, we evaluated the breathing reproducibility (the variation of IM) and the CTV coverage (V_{100}) according to the breathing biofeedback techniques with patient's breathing data instead of 4D CT. Friedman test (repeated measure ANOVA) was performed to analysis the variation of internal motion and CTV coverage (V_{100}) according to repeatedly measured breathing data.

RESULTS

1. Breathing reproducibility

Breathing reproducibility was evaluated by the variation of IM between the first week's breathing data and the subsequent four weeks' breathing data. Fig. 2a and b show the variation of IM between the first week's breathing data and the subsequent four weeks' breathing data for two kinds of definition of IM such as Fig. 2a full motion range and Fig. 2b standard deviation of the position of marker, respectively. For free-breathing, the breathing reproducibility decreased by 28.5% (IM: full motion range) and 27.9% (IM: standard deviation). This is because the breathing cycle was getting irregular during repeated treatment regimes without coaching technique. On the other hand, the breathing reproducibility was improved by 21.4% (IM: full motion range) and 20.7% (IM: standard deviation) for audio-visual biofeedback. This means that audio-visual biofeedback technique is effective method to teach patients how to improve the stability of their breathing. And we realized that the breathing reproducibility can be preserved with audio-instruction. As a result of Friedman test, the result of

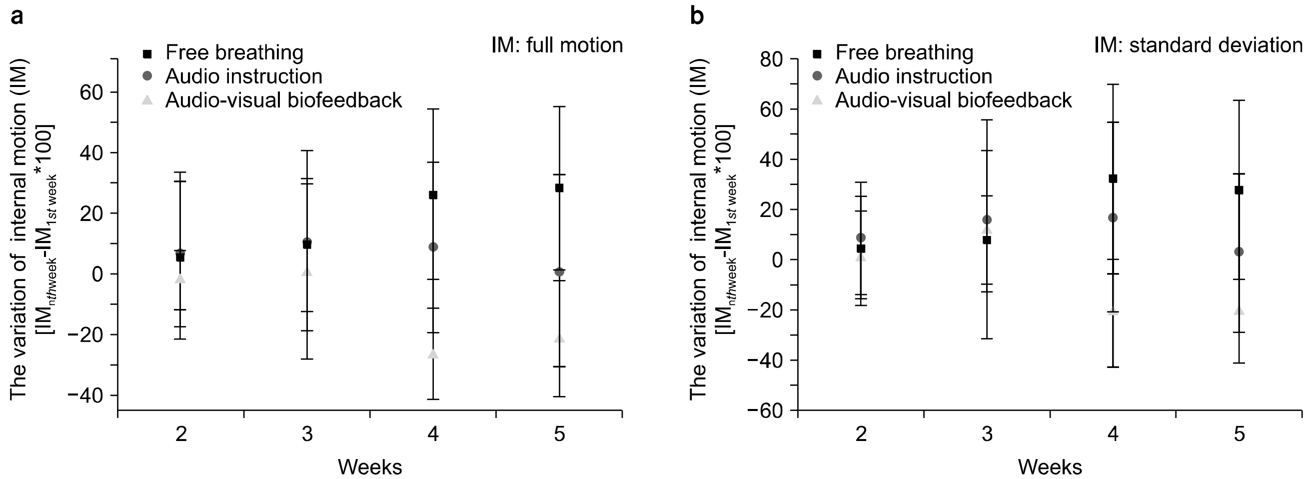

Fig. 2. The variation of IM between the first week's breathing data and the subsequent four weeks' breathing data for two kinds of definition of IM such as (a) full motion range and (b) standard deviation of the position of marker.

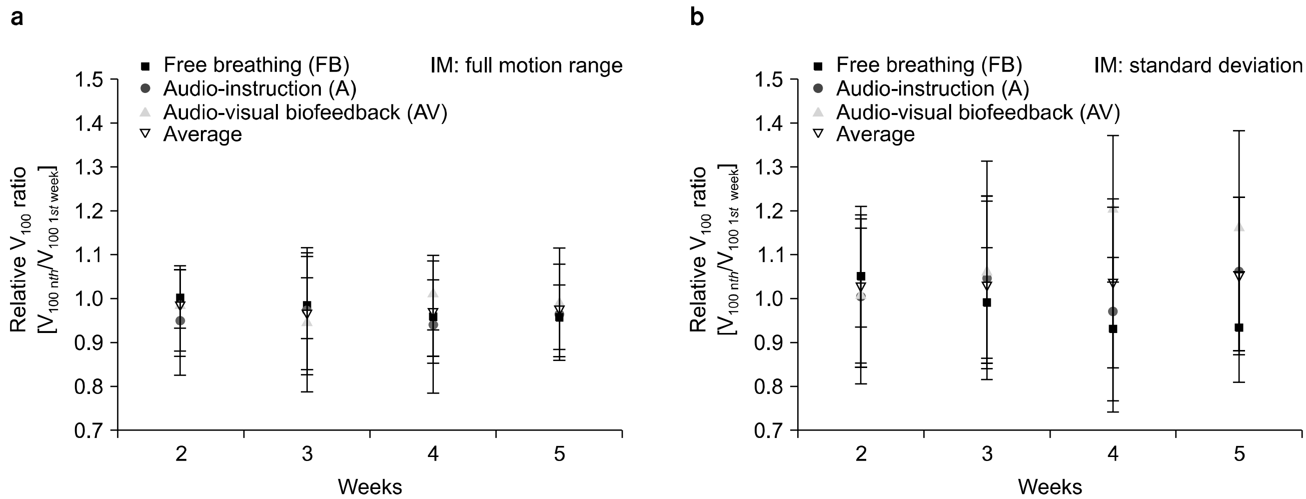

Fig. 3. The ratio of V_{100} between the first week's breathing data and the subsequent four weeks' breathing data for two kinds of definition of IM such as (a) full motion range and (b) standard deviation of the position of marker.

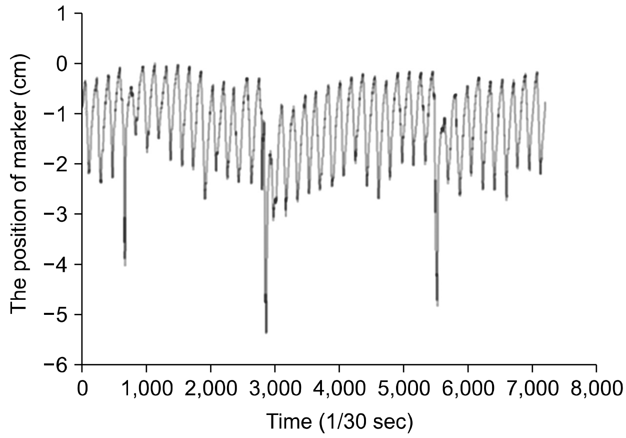

Fig. 4. The patient's breathing data which has intermittently irregular breaths

audio-visual biofeedback technique was statistically significant ($p < 0.05$).

2. Dose evaluation

We evaluated the effects of breathing reproducibility on the CTV coverage. Fig. 3a and b show the ratio of V_{100} between the first week's breathing data and the subsequent four weeks' breathing data for two kinds of definition of IM such as full motion range and standard deviation of the position of marker. In Fig. 3a, remarkable effects of the breathing biofeedback techniques on CTV coverage are not observed. This means that ITV is too large due to intermittently irregular breaths (Fig. 4). In that case, CTV coverage may be fine; however, the large amount of dose is delivered on normal tissue around CTV. In Fig. 3b, the CTV coverage is increased as 20.2% for audio-visual biofeedback while the CTV coverage is decreased as 7.0% for free-breathing. And the CTV coverage is stably preserved within ±4.5% for audio-instruction.

DISCUSSION AND CONCLUSION

We evaluated the effect of the breathing biofeedback techniques on breathing reproducibility and the CTV coverage with a total of nineteen patients' breathing data from Medical College of Virginia (MCV) during repeated treatment regimes. In the result, audio-instruction is effective to maintain patients' breathing stably. And we realized that the audio-visual biofeedback can teach patients how to improve the stability of their breathing. Therefore, CTV coverage and normal tissue comparing are improved effectively with audio-visual biofeedback. In this study, we used the breathing data acquired by the external marker's position instead of 4D CT, therefore, it is expected that our results are a little bit different with the results of 4D CT. However, our results are meaningful to show how breathing biofeedback techniques can improve breathing reproducibility and the CTV coverage during repeated treatment regimes.

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호흡연동 방사선 치료에서 호흡생체자기제어 방식이 호흡 재현성 및 선량에 미치는 영향 평가

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호흡 연동 방사선 치료 시 사용되는 음성 유도 및 음성-영상 유도의 두 가지 호흡생체자기제어 방식이 호흡 재현성 및 선량에 미치는 영향을 평가하였다. 본 연구에서는 Medical College of Virginia (MCV)에서 획득한 19명의 폐암 환자에 대한 호흡 데이터를 이용하였다. 호흡 데이터는 총 5주간 1주 간격으로 자유 호흡, 음성 유도, 음성-영상 유도의 세 가지 형태로 획득하였으며 선량 평가는 MATLAB을 이용하였다. 그 결과, 자유 호흡의 경우에는 반복되는 치료에서 호흡재현성이 감소하여 CTV 선량이 약 30.0% 감소하는 것을 알 수 있었으며, 음성-영상 유도 방식을 이용할 경우 5주 후 CTV 선량이 20.0% 개선됨을 알 수 있었다. 이는 환자가 영상을 통하여 자가호흡조절 능력이 향상되기 때문으로 판단된다. 또한 음성 유도만 사용할 경우에도 호흡재현성을 유지하는 데는 효과적임을 확인하였다.

중심단어: 호흡연동방사선치료, 호흡생체자기제어, 호흡재현성