Measurement of Respiratory Motion Signals for Respiratory Gating Radiation Therapy

*Department of Biomedical Engineering, College of Medicine, The Catholic University of Korea,
[†]Department of Radiation Science, Seoul Health College

Jin-Beom Chung*, Won-Kyun Chung[†], Yon-Lae Kim*, Jeong-Woo Lee*, Tae-Suk Suh*

Respiration motion causes movement of internal structures in the thorax and abdomen, making accurate delivery of radiation therapy to tumors in those areas a challenge. Accounting for such motion during treatment, therefore, has the potential to reduce margins drawn around the clinical target volume (CTV), resulting in a lower dose to normal tissues (e.g., lung and liver) and thus a lower risk of treatment induced complications. Among the techniques that explicitly account for intrafraction motion are breath-hold, respiration gating, and 4D or tumor-tracking techniques. Respiration gating methods periodically turn the beam on when the patient's respiration signal is in a certain part of the respiratory cycle (generally end-inhale or end-exhale). These techniques require acquisition of some form of respiration motion signal (infrared reflective markers, spirometry, strain gauge, thermistor, video tracking of chest outlines and fluoroscopic tracking of implanted markers are some of the techniques employed to date), which is assumed to be correlated with internal anatomy motion. In preliminary study for the respiratory gating radiation therapy, we performed to measurement of this respiration motion signal. In order to measure the respiratory motion signals of patient, respiration measurement system (RMS) was composed with three sensor (spirometer, thermistor, and belt transducer), 4 channel data acquisition system and mobile computer. For two patients, we performed to evaluation of respiratory cycle and shape with RMS. We observed under this system that respiratory cycle is generally periodic but asymmetric, with the majority of time spent. As expected, RMS traced patient's respiration each other well and be easily handled for application.

Key words: Respiration measurement system (RMS), Respiration motion signals, Respiratory gating radiation therapy

INTRODUCTION

Intrafraction motion caused by respiratory is an issue that is becoming increasingly important in the era of image-guided radiotherapy and respiratory gated radiotherapy. The intrafraction motion can be caused by the respiratory, skeletal muscular, cardiac and gastrointestinal systems. Of these three systems, most of the research and development to date has been directed towards accounting for respiration motion. Respiration motion affects all tumor sites of the thorax and abdomen, though the disease of most prevalence and relevance for radiotherapy is lung cancer. Data from imaging studies using CT, fluoroscopy and ultrasound suggest that organs and tumors can move 10～30 mm in the thorax and upper abdomen during the course of the normal breathing cycle.[1-3]

Radiotherapy due to the respiratory motion have three problems: (1) Image acquisition limitations (2) Treatment planning limitations (3) Radiation delivery limitations

If respiratory motion is not accounted for during image acquisition, as is the case when conventional radiotherapy techniques are applied in thoracic and abdominal sites, the motion causes artifacts during image acquisition. These artifacts cause distortion of the target volume and incorrect positional and volumetric information. Treatment planning based on image with incorrect information cause delivery of under-dose on local tumor and over-dose on normal tissue. To solve the problems, the currently suggested method was to respiratory gated radiotherapy.[4] Among the techniques that explicitly account for intra-fraction motion are respiration gating, breath-hold, 4D or tumor-tracking techniques. Breath-hold techniques either actively or passively suspend the patient's respiration and allow treatment during this interval. Respiratory gating method involves the administration of radiation (both during imaging and treatment delivery) within a particular portion of the patient's breathing cycle, commonly referred to as the "gate". These techniques require acquisition of some form of respiration motion signal (infrared reflective markers, spirometry, strain gauge, thermistor, video tracking of chest outlines and fluoroscopic tracking of implanted markers are some of the techniques employed to date), which is assumed to be correlated with internal anatomy motion.

The main aims of our research were to develope technique of respiratory gated radiotherapy with patient's respiratory motion signals. To achieve the final purpose of our research, many steps have been performed. In preliminary study for respiration gating radiation therapy, we performed to process which acquire respiratory signal of the patient and referred to the results for development of respiratory gated radiotherapy.

METHODS AND MATERIALS

1. *Composition of Respiratory measurement system (RMS)*

To measure the patient's breathing, RMS was used in this study. The RMS was composed of mobile PC, four channel data acquisition system, and three sensors (spirometer, thermistor, belt transducer, POWERLAB, USA) which determine the respiratory signals. Fig. 1 shows RMS.

In this paper, the Spirometer front-end (or Spirometer pod) and flow head function as a pneumotachometer, with an output signal proportional to the air flow rate by the patient through a mouthpiece during breathing. The spirometer extension processes this raw signal, applying various corrections to improve accuracy, and displays calibrated flow and volume traces on two channels. The volume V is obtained by integrating the airflow signal f at standard temperature and pressure, so that $V = \int f dt$. As in other spirometric methods, V represents relative lung volume, not absolute volume; the zero level is arbitrary. In spirometry, a nose clip prevents inadvertent nasal breathing. with a little practice, the subject can prevent air leaks around the mouthpiece. spirometery is used clinically to measure lung function, and the American Thoracic Society defines standards for spirometery accuracy.[5]

Fig. 1. Respiratory Measurement System.

Also, RMS provides a convenient means of using thermistors in temperature measurement of respiratory signal. The thermistor provides three important advantages for the respiratory temperature measurement: (1) High sensitivity. There is no difficulty in detecting temperature differences as small as 0.001°C. (2) Size. Thermistors are manufactured in extremely small sizes, allowing measurement in small structures. (3) Response times. Small thermistor structures have very fast response times. The thermistor is that the respiratory signal amplitude corresponds to the room temperature when inhaling and the lung temperature when exhaling.

The piezo respiratory belt transducer in RMS is used to observe respiration by measuring changes in thoracic or abdominal circumference due to respiration. It contains a piezo-electric device that response linearly to change in length. The transducer is a solid-state device that requires no excitation and connects directly to a BNC input. The data acquired by the transducer can indicate inhalation, expiration, breathing strength and can be used to derive breathing rate.

2. Measurement of respiratory signals

To assess respiratory motion signals, the RMS measurements of two patients (1 man and 1 woman) were performed with each sensors (Spirometer, thermistor, belt-transducer) in respiratory type and pattern. Measurement time of the each sensors determined to 1 min which patients have not particularly difficulty for an experiment.

The procedures for measuring respiration motion signal were performed under following condition. In case of Spirometer and thermistor, after sensors were placed on the patient, respiratory signals were measured in patient's respiratory pattern of deep and normal breathing. Breathing, measurement of pizeo respiratory belt transducer was added to the type of thoracic and abdominal respiratory in two respiratory type.

RESULTS

The respiration motion signals can be described respiration volume, respiration temperature, and displacement in abdomen and thorax caused due to patient's breathing. The signals have been measured as respiratory type and mode to two patient by using RSM. Because the signals are measured or simulated as a function of time, breathing motion is also known as a function of time. Fig. 2 shows the respiration volume which trace the respiratory waveform against time by application of spi-rometer at deep and normal breathing of two patients.

In respiratory waveform of patient 2 in Fig. 2, the a point is position at exhale of respiration and b point is position at inhale of respiration. The c period is a breathing cycle. The breathing cycle is 1.5 sec. Erratic signal of a dotted circle line represents

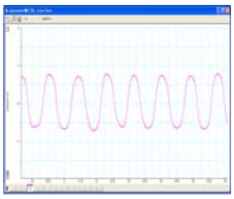
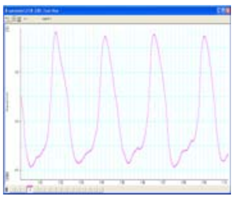
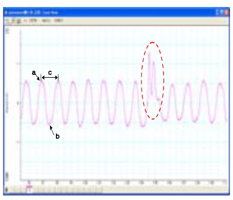
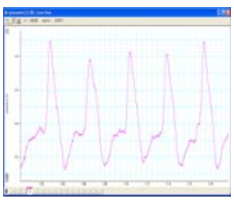
Type	Normal respiration	Deep respiration
Patient 1		
Patient 2		

Fig. 2. Data of respiration volume acquired by application of spiromerter at deep and normal respiration.

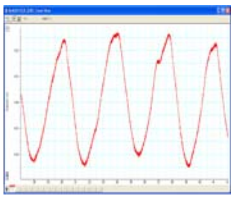
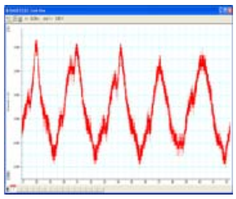
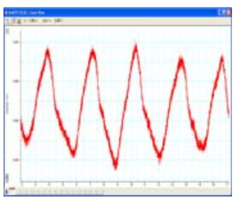
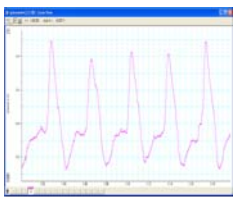
Type	Deep respiration	Normal respiration
Thoracic respiration		
Abdominal respiration		

Fig. 3. Displacement of abdomen and thorax acquired by using piezo respiratory belt transducer at type and mode of respiratory.

the signal of respiratory volume due to coughing. Fig. 3 presents the results of respiratory waveform at variation of respiratory mode with pizeo respiratory belt transducer. The respiration mode was classified to respiration of thorax and abdomen. Fig. 4 is respiration waveform acquired with thermistor. The a point is the air temperature when a patient exhale and b point is that when exhaling. A large variation of air temperature shows when patient are deep breathing.

DISCUSSION AND CONCLUSION

Many gated, breath-hold and 4D radiation therapy techniques rely on using a respiration signal as a surrogate for or predictor of internal tumor motion. The respiratory signals can be measured by application of many methods. Of these methods, we performed to measure of respiratory signals with sensors. The method was designed in 1999 by Hideo D. Cubo.[2] As expected, the RMS traced patient's respiration each other well and be easily handled for application.

In future study, three processes are need to achieve main purpose of our research; first step is to assessment of internal anatomy motion though analysis of image acquired by the fluoroscopy, ultrasound. That can verify the correlation between respiration signals and internal anatomy motion. Second step is to the synchronized beam control with the respiratory signals acquired by RMS. In the final step we would be verified dose distribution of the synchronized beam by using dynamic phantom which reproduce respiration motion.

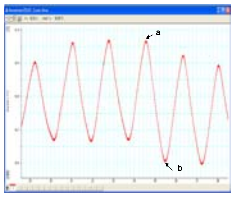
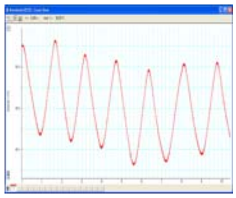
Type	Deep respiration	Normal respiration
Patient		

Fig. 4. Data of respiration temperature by application of thermistor at deep and normal respiration.

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호흡동조 방사선치료를 위한 호흡 움직임 신호 측정

*가톨릭대학교 의과대학 의공학교실, †서울 보건대학 방사선과

정진범*, 정원균*, 김연래†, 이정우*, 서태석*

호흡 움직임은 종양에 대한 방사선치료의 부정확한 방사선조사가 유도되도록 복부 및 흉부에서 움직임을 야기한다. 그러므로 치료시 이러한 움직임에 대한 정확한 계산은 정상조직에는 저 선량을 조사되도록 CTV의 마진을 줄일 수 있고 방사선치료에 발생되는 부작용을 줄일 수 있다. Intrafraction motion을 고려하는 기술로는 호흡멈춤, 호흡동조, 4차원 또는 종양추적 기술이 있다. 호흡동조 방법은 환자의 호흡 신호가 호흡주기의 일정한 범위에 위치할 때 주기적으로 빔을 조사하고 그 범위를 벗어날 때는 빔을 조사하지 않는 방법이다. 이러한 기술은 내부장기 움직임과 상관관계가 있는 호흡 움직임 신호의 획득이 요구된다. 호흡동조 방사선치료를 위한 예비연구로 본 연구자들은 호흡 움직임 신호 측정을 수행하였다. 환자의 호흡 움직임 신호 측정을 위해서, 호흡측정시스템을 3 가지 센서, 4 채널 데이터 획득 시스템, 신호처리용 컴퓨터로 구성하였다. 2명의 환자를 대상으로 본 연구자들은 호흡측정시스템을 가지고 호흡주기 및 파형을 평가하였다. 그 결과 호흡주기는 시간의 함수에 따라 일반적으로 정확한 대칭 형태는 아니지만 주기적인 형태로 측정되었다. 호흡측정 시스템은 기대했던 만큼 환자의 호흡을 잘 추적하였으며 실험에 적용하기 위해 쉽게 컨트롤 할 수 있었다.

중심단어: 호흡측정시스템, 호흡움직임신호, 호흡동조 방사선치료