Measurement of Variation in Water Equivalent Path Length by Respiratory Organ Movement

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ABSTRACT

In particle radiotherapy, a shape of the beam to conform the irradiation field is statically defined by the compensator, collimator and potal devices at the outside of the patient body. However the target such as lung or liver cancer moves along with respiration. This increases the irradiated volume of normal tissue. Prior discussions about organ motions along with respiration have been mainly focused on inferior-superior movement that was usually perpendicular to beam axis. On the other hand, the change of the target depth along the beam axis is very important especially in particle radiotherapy, because the range end of beam (Bragg peak) is so sharp as to be matched to distal edge of the target. In treatment planning, the range of the particle beam inside the body is calculated using a calibration curve relating CT number and water equivalent path length (WEL) to correct the inhomogeneities of tissues. The variation in CT number along the beam path would cause the uncertainties of range calculation at treatment planning for particle radiotherapy. To estimate the uncertainties of the range calculation associated with patient breathing, we proposed the method using sequential CT images with respiration waveform, and analyzed organ motions and WELs at patients that had lung or liver cancer. The variation of the depth along the beam path was presented in WEL rather than geometrical length. In analyzed cases, WELs around the diaphragm were remarkably changed depending on the respiration, and the magnitude of these WEL variations was almost comparable to inferior-superior movement of diaphragm. The variation of WEL around the lung was influenced by heartbeat.

Keywords: Organ motion, dynamic CT images, Water equivalent path length

1. INTRODUCTION

Advantages in the use of heavy charged particles for radiotherapy is the high potential to concentrate a uniform prescribed dose to the target volume while minimizing irradiation to surrounding normal tissues. This is to the unique depth dose distribution known as the Bragg peak and less scattering in matter (1). We have carried out clinical trial at HIMAC (Heavy Ion Medical Accelerator in Chiba) using the carbon beam and already treated about 1200 patients since 1994. In treatment planning of particle radiotherapy, a target region is interactively registered onto a set of three-dimensional CT images. Then irradiation fields are set so as to give the prescribed dose to target region and to spare surrounding critical organs. A dose distribution is calculated for the filed, and shapes of the compensator and the collimator are calculated to realize the dose distribution at each irradiation field (2). Here range of the particle beam inside the body is calculated with a calibration curve relating CT number and water equivalent length (WEL) to correct the inhomogeneities of tissues (3). The conformal shape of the irradiation filed is statically defined by the compensator, the collimator and portal devices at the outside of patient body (1). However the target such as lung or liver cancer moves along with respiration. This increases the irradiated volume of normal tissue. To overcome this, the gated irradiation is one of the useful methods and several researches have been reported (4). In HIMAC we developed a total treatment system of gated irradiation for heavy-ion radiotherapy, over 250 patients had already been treated by this system since 1996 (5). Prior discussions about organ motions along with respiration have been focused on the motion along the body axis that was usually perpendicular to beam axis. Similarly, the change of the target depth along the beam axis is very important especially in particle radiotherapy, because the shape end of beam (Bragg peak) is so sharp as to be matched to the distal edge of the target. The change of range end may be occurred by geometrical movements of organs within beam path. In this study, we will describe the method to measure the change of target depth and discuss about the variation in WEL with patient breathing.

2. MATERIALS AND METHODS

The dynamic scanning mode of a helical x-ray CT scanner (Toshiba Co., X-force SH) was used to accumulate the continuous x-ray projection data. In this CT scanner an x-ray source on the CT gantry was continuously rotating around the patient and it took 1second for each rotation. Continuous projection data at same slice position was accumulated while the patient breathed freely. We reconstructed each CT image at every 0.2 seconds using continuous projection data for 0.5 seconds (half scan image). The slice thickness was 3 mm. Image size was 512x512 pixels and each pixel was 0.78mm square. The respiratory sensor that was routinely used to gated irradiation at HIMAC was set on the patient (5). In our respiratory sensing system, the motion of a patient's organ during respiration was detected as the motion of the body surface. At the same time with acquisition of projection data, the on/off signal of x-ray exposure on the CT scanner and the respiratory signal from the respiratory sensor were recorded. The on-time of X-ray exposure corresponded with the start of data acquisition for CT images, and that timing was related to the phase of respiration. These CT images were analyzed in our treatment planning system that included the function converting CT number to WEL (2). There we measured the geometrical size of an organ and the WEL at interested points in each CT image. CT images of two patients were analyzed here. One patient had the liver cancer at the upper right lobe, and another patient had the lung cancer.

3. RESULTS

3.1 Liver case

Figure 1 shows results of change in liver size and WEL with respiration waveform. In this case, the position of CT slice included the beam iso-center of treatment planning for this patient, and intersected the diaphragm. The geometrical length of liver size along the anterior-posterior direction was measured at each CT image. WELs betweens the iso-center and body surfaces of front and back were analyzed. The maximum change in size of liver was 35.2mm. Changes in WEL from the iso-center to the front and the back were 6.2 mm and 18.9 mm, respectively. The phase of respiration waveform was delayed by about 0.3 seconds from that WELs.

3.2 Lung case

In lung case, we measured WEL of the lung size. Figure 2 shows the variation of the WEL with respiration waveform. The maximum change of WEL was 5.0 mm while that of geometrical length was less than 1 mm. Though the respiration waveform seemed to be periodic, the pattern of change in WEL was very complicated in comparison with liver case. Then we analyzed the power spectrum of graphs in figure 2. Figure 3 shows the result of power spectrum. The power spectrum of change in WEL had two peaks at 0.37Hz and 0.98Hz, while the respiration waveform had one conspicuous peak at 0.37Hz.

4. DISSCUSION AND CONCLUSION

In the case of liver region, WELs around the diaphragm was remarkably changed depending on the respiratory organ movement. The magnitude of these variations was comparable to the motion along the body axis. The CT number between the liver (about 0) and the lung (about –700) is very different. In the case that the beam path crosses the liver and the lung around the diaphragm, WEL along the beam path will dynamically change by the movement of diaphragm position. However change in WEL and liver size correlated with respiratory signal that was detected on the body surface. In the case of lung region, the correlation between the change in WEL of lung size and the respiratory signal appeared not to be clear. In results of frequency analysis, one of frequency components of WEL, 0.37Hz, corresponded with the frequency component of respiration waveform. Another frequency component, 0.98Hz (about 1 sec./cycle) was presumed to be a frequency of heartbeat. Although the effect of motion by heartbeat was not considered on the gated irradiation at present, this effect could be included in CT images for treatment planning. Because each CT image includes the averaged organ motion over one second (full scan image), even the gated CT. To estimate the maximum depth variation in target region, we need several sets of sequential CT images at different slice positions. This is technically possible, but the medical exposure to patient is increase. Recent progress in multi-slice CT scanner might contribute to solve this problem. In conclusion, variations of the depth along the beam path were presented in WEL rather than geometrical length. WELs around the diaphragm were remarkably changed depending on the respiration, and the magnitude of these WEL variations was almost comparable to inferior-superior movement of diaphragm. In addition, the variation of WEL around the lung was influenced by heartbeat. The method described here would be useful to decide the depth margin along the beam path at the treatment planning for gated irradiation.

REFERENCES

1. T. Kanai, M. Endo, S. Minohara, et al., "Biophysical characteristics of HIMAC clinical irradiation system for heavy-ion radiation therapy", *Int J Radiat Oncol Biol Phys.,* 44:201-210, 1999.
2. M. Endo, H. Koyama-Ito, S. Minohara, et al., "HIPLAN-a heavy ion treatment planning system at HIMAC", *J. Jpn Soc Ther Radiol Oncol.,* 8:231-238, 1996.
3. N. Matsufuji , H. Tomura, Y. Futami, et al., "Relationship between CT number and electron density, scatter angle and nuclear reaction for hadron-therapy treatment planning", *Phys Med Biol.,* 43:3261-3275, 1998.
4. K.M. Langen, D.TL. Jones, "Organ motion and its management", *Int J Radiat Oncol Biol Phys.,* 50:265-278, 2001.
5. S. Minohara , T. Kanai, M. Endo, et al., "Respiratory gated irradiation system for heavy-ion radiotherapy", *Int J Radiat Oncol Biol Phys.,* 47:1097-1103, 2000.

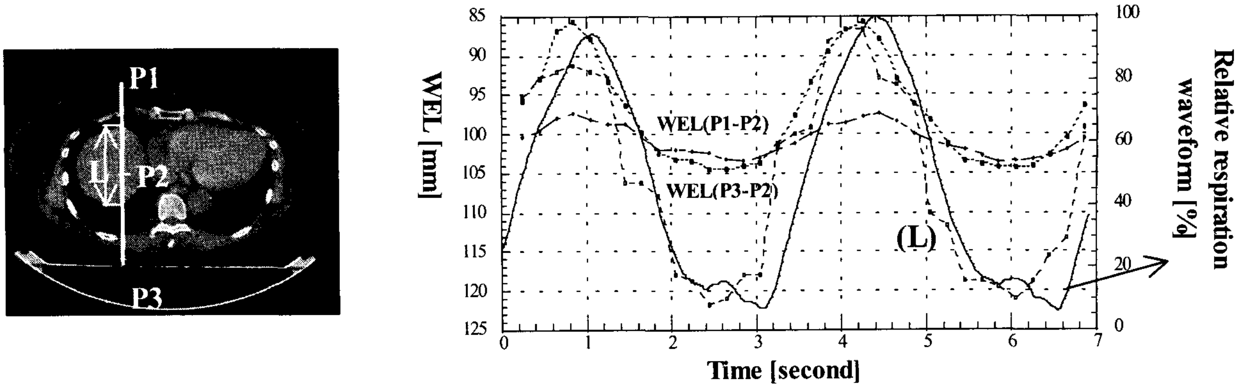

Figure 1: Change in WELs along the anterior-posterior path and the respiration waveform (solid line)
Left picture was one of the sequential CT images, and illustrated measured points. WELs (P1-P2, P3-P2) and Liver size (L) were analyzed with the respiration waveform.

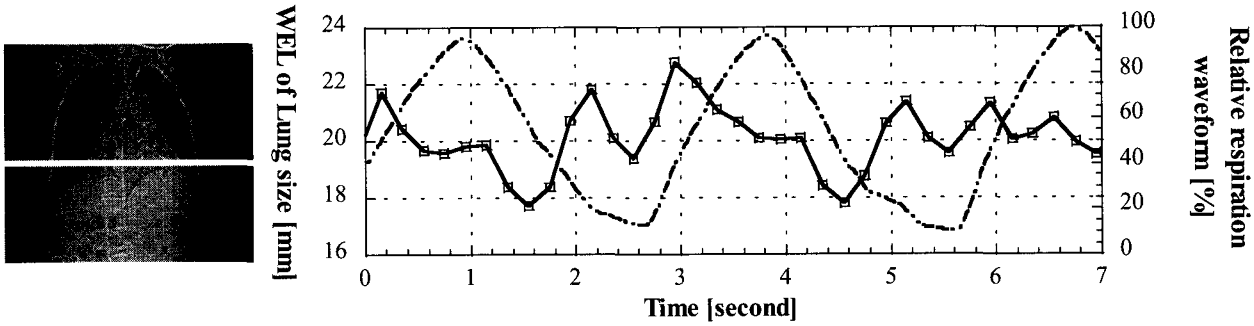

Figure 2: Change in WEL of lung size (solid line) and the respiration waveform (doted line). Left figure shows the slice position of CT images on the scout view image

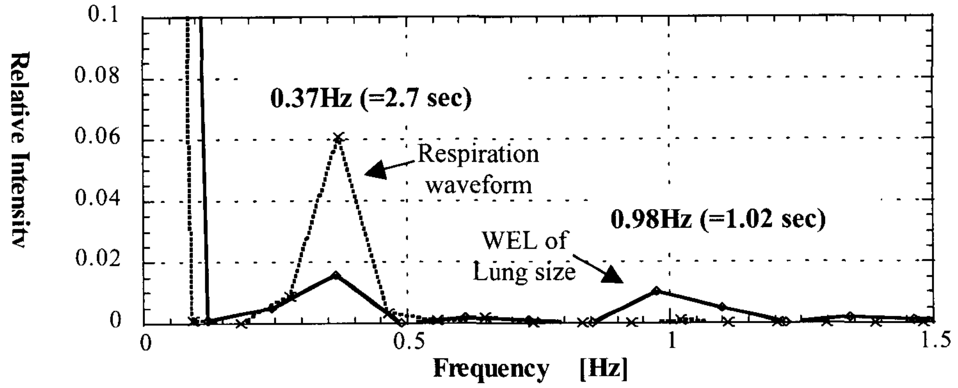

Figure 3: Frequency analysis of graphs in figure 2.
Power spectrums of the respiration waveform and the WEL of lung size were shown.