Synchronous monitoring of external/internal respiratory motion: validity of respiration-gated radiotherapy for liver tumors

Takeshi Nishioka · Seiko Nishioka · Masaki Kawahara · Shigeru Tanaka · Hiroki Shirato · Ken Nishi · Tadao Hiromura

Abstract

Purpose. Four-dimensional (4D) radiotherapy, in particular respiration gating for the treatment of lung tumors, is gaining popularity. Its utility for other sites, however, has not been investigated fully. The purpose of this study was to see whether 4D therapy is feasible for liver tumors.

Material and methods. Six patients (five with hepatomas and one with metastatic liver tumor) had a fiducial, gold marker 1.5 mm in diameter implanted in the vicinity of their liver tumors. The inner and external (i.e., upper abdominal wall) respiratory movements were simultaneously recorded using a real-time tumor-tracking radiotherapy system and respiration monitor equipment applied to the mid to upper abdomen.

Results. The fluctuations from the baseline position of liver tumors were small; the mean absolute value was 3.92 ± 1.94 mm. The mean right–left, anteroposterior, and craniocaudal total movements were 4.19 ± 2.46, 7.23 ± 2.96, and 15.98 ± 6.02 mm, respectively. The phase shift was negligible.

Conclusion. Liver tumors may be suitable for respiration-gated radiotherapy, and they may become curable with 4D radiotherapy.

Key words Gated radiotherapy · Exhale fluctuation · Liver cancer · Respiration · Radiotherapy

Introduction

We previously reported a pitfall of respiration-gated radiotherapy of lung tumors. In brief, in our system radiation beams are turned on when a respiratory monitor detects an end-exhale signal from the external anatomy, the mid to upper abdomen. However, the position of a tumor can vary among end-exhalas, depending on the tumor site, patient’s condition, and the treatment session. Variation may cause an underdose to the tumor or an overdose to the surrounding lung tissues. The implications from that study were that we should watch the end-exhale positions of external respiratory waves carefully on a monitor; and if an unexpected large shift is observed on end-exhale positions, we should interrupt the treatment session and seek the reason for the shift. Reasons include an influence of coexisting lung disease, lung segment volume inflation varying among respiration cycles, unexpected movements depending on tumor sites (i.e., tumors near the heart), or more problematically, patients suddenly falling into a deep sleep. The latter condition requires us to awaken patients and ask them to achieve stable breathing. The former conditions could require replanning, taking the shift into consideration for the planning target volume (PTV) determination.
tion. In the present study, to clarify respiratory liver tumor motion for four-dimensional radiotherapy, we used the same synchronous dual internal/external monitoring system as we did for the lung. The system enabled us to produce the position wave of a fiducial implanted in the liver and to correlate it with the respiratory wave of the mid to upper abdomen.

Materials and methods

The real-time tumor-tracking radiotherapy (RTRT) system developed by Mitsubishi Co. and Shirato and colleagues,2,3 was used to detect fiducials implanted into the liver. Six patients (five with hepatomas and one with metastatic liver tumor) had a fiducial, gold marker 1.5 mm in diameter implanted in the vicinity of their liver tumors under ultrasound (US) guidance. Informed consent was obtained from all patients, and the study was approved by the institutional ethics committee. All of the patients were male, and their age ranged from 58 to 68 years (mean 62 years). The fiducial locations were in the right lobe of the liver in all six patients. A respiratory gating system (Anzai Medical, Tokyo, Japan) was applied on the mid to upper abdomen to detect respiratory motion (i.e., amplitude and phase).

The details of our dual synchronous internal/external monitoring were described previously.1 Six to eight stereotactic conformal beams were used to treat the patients with a typical dose-fractional schedule of 40 Gy in four fractions. A 4-MV linac machine designed specifically for the RTRT system was used for the treatment. Patients were treated during free breathing, and the therapy was carried out using the RTRT system; that is, the respiration gating in this study was imaginary, and it was solely for the purpose of testing the validity of respiration gating for the liver. At the time of computed tomography (CT) examination and with the patient on the treatment couch, the patient was first asked by the medical staff to perform shallow, stable breathing. The CT examination and treatment started only after the patient’s breathing waves became regular and small, which was confirmed by the radiation oncologist in charge. This process was usually finished within a few minutes. This treatment preparation was the same for both the lung and the liver.

For the respiration-gating window, we used 30% amplitude from the baseline, a line connecting at least 50 end-exhale points of the external wave. The major concern in the present study was whether the baseline was stable because it is crucial for respiration-gated radiotherapy, as mentioned above. The respiratory wave was correlated to the position of the fiducial recorded by the RTRT system; thereby, we could obtain (1) the degree of baseline fluctuation of the external wave (translated into fiducial fluctuation in millimeters), (2) the total movement of fiducials, and (3) the phase difference between the fiducial wave and the external waves. With regard to the baseline fluctuation and phase shift, the data for 24 lung fiducials were used for comparison. Student’s t-test was used to compare the means of the two groups.

Results

Degree of baseline fluctuation

The baseline fluctuation was surprisingly small for all six patients (Fig. 1). The mean absolute value was 3.92 ± 1.94 mm for liver tumors. Figure 1 suggests that the end-exhale respiratory wave positions of the liver were stable and correlated well with the end-exhale positions of the fiducial waves recorded by the RTRT system. For comparison with the lung, we show the baseline fluctuations of 24 fiducials implanted in 18 patients. The mean absolute value was 6.82 ± 2.21 mm (statistically not significant).

Total movement of fiducials

The mean right–left, anteroposterior, and craniocaudal total movements were 4.19 ± 2.46, 7.23 ± 2.96, and 15.98 ± 6.02 mm, respectively. As expected, the movement was largest in the craniocaudal direction. In the imaginary respiration-gated radiotherapy, the position of the fiducials fell within 30% amplitude of their total movements in half of the patients. For the reminder of the patients,