PATIENT TRAINING IN RESPIRATORY-GATED RADIOTHERAPY

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(Accepted 15 January 2002)

Abstract—Respiratory gating is used to counter the effects of organ motion during radiotherapy for chest tumors. The effects of variations in patient breathing patterns during a single treatment and from day to day are unknown. We evaluated the feasibility of using patient training tools and their effect on the breathing cycle regularity and reproducibility during respiratory-gated radiotherapy. To monitor respiratory patterns, we used a component of a commercially available respiratory-gated radiotherapy system (Real Time Position Management (RPM) System, Varian Oncology Systems, Palo Alto, CA 94304). This passive marker video tracking system consists of reflective markers placed on the patient’s chest or abdomen, which are detected by a wall-mounted video camera. Software installed on a PC interfaced to this camera detects the marker motion digitally and records it. The marker position as a function of time serves as the motion signal that may be used to trigger imaging or treatment. The training tools used were audio prompting and visual feedback, with free breathing as a control. The audio prompting method used instructions to “breathe in” or “breathe out” at periodic intervals deduced from patients’ own breathing patterns. In the visual feedback method, patients were shown a real-time trace of their abdominal wall motion due to breathing. Using this, they were asked to maintain a constant amplitude of motion. Motion traces of the abdominal wall were recorded for each patient for various maneuvers. Free breathing showed a variable amplitude and frequency. Audio prompting resulted in a reproducible frequency; however, the variability and the magnitude of amplitude increased. Visual feedback gave a better control over the amplitude but showed minor variations in frequency. We concluded that training improves the reproducibility of amplitude and frequency of patient breathing cycles. This may increase the accuracy of respiratory-gated radiation therapy. © 2003 American Association of Medical Dosimetrists.

Key Words: Respiratory gating, Radiotherapy, Chest tumors, Patient training.

INTRODUCTION

Normal tissue toxicity encountered in lung cancer radiotherapy is frequently due to large treatment margins. Respiratory motion necessitates that large margins be added to the clinical target volume to ensure adequate dose coverage during the entire range of motion of the tumor. This intrafraction organ motion forms a critical component of treatment margins in chest radiotherapy. Decreasing such motion may lead to significant gains in chest radiotherapy. Some reports have analyzed the potential for dose escalation if the respiratory component of the PTV (planning target volume) were eliminated. Secondly, intensity-modulated radiation therapy (IMRT) attempts to reduce normal tissue toxicity while simultaneously allowing potential dose escalation. However, the motion artifacts resulting from breathing motion may compromise the effectiveness of IMRT. Various developments that aim to reduce the negative effects of respiratory organ motion are actively being investigated as adjuncts to the use of 3DCRT or IMRT for chest tumors.

These techniques are most effective when the patient’s breathing pattern during imaging and treatment is reproducible. However, without any external intervention, patients cannot voluntarily maintain a stable breathing pattern and reproduce this pattern from day to day. Some reports have attempted to characterize organ motion using various imaging modalities. However, many analyses do not address the critical aspect of temporal variation in breathing patterns and the effect on treatment. To further study this very important issue related to most modern techniques of chest radiotherapy, we evaluated the technical feasibility and effect of using training tools on respiratory patterns.

METHODS AND MATERIALS

The respiratory motion monitoring system employed in our investigations is a component of a commercially available respiratory-gated radiotherapy system (Real Time Position Management (RPM) System, Varian Oncology Systems, Palo Alto, CA 94304). A small lightweight hollow plastic box of 6.5 × 3.5 × 4 cm³ with 2 or more retroreflective marker dots, each approximately 5 mm in diameter, is used. This box is placed on the patient at a spot where the amplitude of respiratory motion is high, usually the midpoint between the xyphoid process and the umbilicus. Tatoos, permanent ink, or measurements may be used to precisely
reposition this marker on a daily basis. A combined camera and infrared illuminator unit is mounted on one of the walls of the simulator computed tomography (CT)/treatment room, as shown in Fig. 1. The illuminator floods the marker with infrared light, and the camera, which is interfaced to a personal computer (PC) records the reflection of the dots on the marker. The software installed on the PC digitally records the position of the reflective dots from the camera image at 30 Hz. This position trace, as a function of time, serves as the respiratory signal.

Patients were trained to regulate their breathing patterns. Graphical traces of respiratory patterns were recorded using “free breathing,” “audio prompting,” and “visual feedback” modes. These concepts are defined below.

**Free breathing**

The patient is instructed to breathe as he/she usually does at rest. No modifications to his/her breathing pattern are suggested.

**Audio prompting**

This technique involves using a computer-generated prerecorded message that instructs the patient to “breathe in” or “breathe out” at periodic intervals. This tool is pre-installed in the commercially available version of the motion monitoring system. The PC processes the feedback from the respiratory motion trace during the patient’s first few breathing cycles. Based on this information, the PC determines the rate at which the patient can comfortably breathe and “instructs” the patient to breathe in and breathe out.

**Visual feedback**

At our institution, we have developed and incorporated a visual feedback training tool. This tool consists of an LCD monitor positioned near the patient (Fig. 1). The patient can see a continuous trace of his or her own breathing pattern. He/she is then instructed to perform various breathing maneuvers while looking at the breathing trace on the LCD monitor. This arrangement allowed us to set an upper and a lower “threshold line” on the real-time graphic trace of the abdominal wall motion. The patient is then instructed to limit the amplitude of breathing and hence that of the abdominal motion between these thresholds.

Five patients who were on treatment with conventional radiotherapy for chest malignancies underwent monitoring. Each patient performed the following breathing maneuvers at least once: free breathing, breathing using audio prompting, and breathing using visual feedback. The motion traces were then compared to each other with respect to the range of motion and the effect of training on the breathing patterns. An implicit assumption with the gating system used is that the abdominal marker motion correlates to the tumor motion. For the purpose of this study, we accepted this assumption.

**RESULTS**

Figures 2, 3, and 4 show a sample comparison of breathing traces for free breathing, breathing using audio prompting, and breathing using visual feedback, respectively, over different sessions for patient no. 5. As shown in Fig. 2, during free breathing, i.e., without any form of coaching, breathing patterns showed poor reproducibility in frequency and amplitude. This was also evident on consecutive monitoring sessions on the same patient.

As shown in Fig. 3, with audio prompting, patients
were able to reproduce the frequency of respiration, and more regular pattern of respiration was seen. However, we noticed an increase in the amplitude of motion of the anterior abdominal wall. Furthermore, the amplitude was not always the same during the same session, and varied even more markedly from one session to the next. Patients were able to achieve a good control over the amplitude of motion of the anterior abdominal wall with visual feedback (Fig. 4); however, the frequency of breathing cycles was variable with this technique.

The bar chart shown in Fig. 5 provides a quantitative analysis of the differences between untrained and trained respiratory patterns in patient no. 5. This figure shows the average breathing period (time elapsed between consecutive minima, averaged over one session) for the same patient for 4 different sessions. It is clear that the average breathing period for audio prompting varies much less compared to visual feedback mode. Free breathing shows the most variation in time period.

The data for all 5 patients is summarized in Figs. 6 through 8. Figure 6 shows that the range of motion is generally significantly smaller for visual feedback mode as compared to audio prompting mode. Figures 7 and 8 show intra- and inter-session variability of range of motion and breathing period in terms of their standard deviations (composite of all sessions), respectively. The data for the first patient was acquired while developing the procedures and likely represents an effect of our learning curve. For visual feedback, the variability in the range of motion for patient nos. 2 through 5 is small. For audio prompting, it can be more variable, indicating the reduced control over breathing amplitude in this mode. Similarly, except for the first patient, the breathing period variability is small for audio prompting but can be more variable for the visual feedback.

**DISCUSSION**

We have evaluated the feasibility of using various training tools and their effect on respiratory patterns. This may allow us to fashion gated radiotherapy with a higher level of confidence. Patients were able to tolerate these maneuvers well and follow instructions when audio prompting or visual feedback techniques were utilized.

Three-dimensional conformal radiation therapy planning typically takes into account the range of motion of the tumor during a breathing cycle by assigning a portion of the margin to this motion. (See, for example, RTOG 93-11 protocol for non-small cell lung cancers.)
A fluoroscopic simulation provides a reasonable magnitude of this range of motion. However, we found that this range may vary during a single treatment fraction (Fig. 2) as well as between treatment fractions, i.e., from day to day, in the same patient. This could conceivably alter the coverage of the tumor if the PTV is based on a single fluoroscopy session. More commonly, however, CT-based planning uses published numbers to assign a value for the intrafraction range of motion of the tumor. This could prove to be equally inaccurate. Currently, it is not clear what role respiratory motion plays on dose-volume histogram (DVHs) and isodose coverage of the target. Newer treatment techniques such as IMRT and respiratory-gated therapy attempt to decrease treatment margins. If daily variations in patient breathing patterns are not acknowledged while using such techniques, PTVs based on a single imaging study could possibly underdose the target and/or overdose normal tissues.

Audio prompting improved the frequency of breathing, but resulted in a variation in the amplitude of motion (Figs. 3, 5, and 8). The impact of an increase in the range of motion of the tumor depends on the treatment technique. Most new techniques aim to decrease the portion of the PTV that accounts for the intrafraction motion. If the target has a greater range of motion, a larger volume of normal tissue has to be included in the PTV to account for this motion. This would increase the toxicity of conventional (non-gated) radiotherapy. This increase in amplitude could also have a negative impact on the logistics involved in administering gated radiotherapy. The Varian respiratory-gating system is based on the principle of turning the radiotherapy beam on and off depending upon the position of the target. As such, any portion of the breathing cycle may be used to treat the target, based on the amplitude of motion of the target. If the amplitude of motion is large, a smaller portion of a single breathing cycle may be used to treat in a gated fashion to reduce the volume of normal tissue irradiated. Conceivably, a larger number of breathing cycles would then be required to deliver the same number of monitor units using gating. Thus, the increase in amplitude with audio prompting could prove to be detrimental to patient throughput by increasing treatment time.

Showing patients a trace of their respiratory excursion seemed to be the logical method to accomplish control over the variation in the amplitude of motion. Visual feedback was more successful in controlling the amplitude of breathing motion in most patients. While the concept of using video training has previously been mentioned, quantitative studies of this method are not available. This could perhaps be attributed to overcom-
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compensation by patients when they saw the trace approaching the “thresholds” set by the operator. We should note, however, that constancy of amplitude is much more important for gated treatments than constancy of frequency. Furthermore, visual feedback may also allow the patient to hold his or her breath at a predefined reproducible level, i.e., a “gated breath-hold” mode of imaging and treatments. Because audio prompting can reproduce the frequency of the patient’s breathing cycle and visual feedback can limit the amplitude of motion, all aspects of the patient’s respiratory pattern could, in principle, be made reproducible with adequate coaching.

CONCLUSIONS

We concluded that training improves the reproducibility of amplitude and frequency of patient breathing cycles. This may increase the accuracy of respiratory-gated radiation therapy.

REFERENCES