THE CLINICAL IMPLEMENTATION OF RESPIRATORY-GATED INTENSITY-MODULATED RADIOTHERAPY

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Abstract—The clinical use of respiratory-gated radiotherapy and the application of intensity-modulated radiotherapy (IMRT) are 2 relatively new innovations to the treatment of lung cancer. Respiratory gating can reduce the deleterious effects of intrafraction motion, and IMRT can concurrently increase tumor dose homogeneity and reduce dose to critical structures including the lungs, spinal cord, esophagus, and heart. The aim of this work is to describe the clinical implementation of respiratory-gated IMRT for the treatment of non-small cell lung cancer. Documented clinical procedures were developed to include a tumor motion study, gated CT imaging, IMRT treatment planning, and gated IMRT delivery. Treatment planning procedures for respiratory-gated IMRT including beam arrangements and dose-volume constraints were developed. Quality assurance procedures were designed to quantify both the dosimetric and positional accuracy of respiratory-gated IMRT, including film dosimetry dose measurements and Monte Carlo dose calculations for verification and validation of individual patient treatments. Respiratory-gated IMRT is accepted by both treatment staff and patients. The dosimetric and positional quality assurance test results indicate that respiratory-gated IMRT can be delivered accurately. If carefully implemented, respiratory-gated IMRT is a practical alternative to conventional thoracic radiotherapy.

For mobile tumors, respiratory-gated radiotherapy is used as the standard of care at our institution. Due to the increased workload, the choice of IMRT is taken on a case-by-case basis, with approximately half of the non-small cell lung cancer patients receiving respiratory-gated IMRT. We are currently evaluating whether superior tumor coverage and limited normal tissue dosing will lead to improvements in local control and survival in non-small cell lung cancer. © 2006 American Association of Medical Dosimetrists.

Key Words: IMRT, lung cancer, respiratory-gated IMRT.

INTRODUCTION

Lung cancer causes more deaths in the United States than any other cancer and more than the next 3 cancers combined.1 Despite significant efforts to improve treatment, 5-year lung cancer survival remains at around 15%.1 A recent RTOG retrospective analysis of 1290 NSCLC patients demonstrates that every 10-Gy increase in biologically equivalent dose (BED) results in an 18% decrease in the risk of death,2 clearly demonstrating the need for dose intensification. Martel et al.3 estimate from their data that to achieve 50% local progression-free survival at 30 months, 85 Gy—a dose level considerably higher than the current standard of care—will be required (in 2-Gy fractions). Stereotactic hypofractionated early-stage NSCLC regimens also show a dose-response.4,5 The cost of dose intensification is normal tissue toxicity, which has been shown to have a dose-response for the lung,6–11 heart,12 and esophagus.13,14

Lung tumors move with respiration15–20 up to 5 cm for free breathing;21 however, the magnitude of motion is variable and unpredictable.26 Thus, respiratory motion management is one of the key components required to test the hypothesis of Ling et al.27 that technologic innovations will improve radiotherapy of non-small cell lung cancer, and enable radiotherapy to rival post-surgical outcomes.28 Respiratory gating19–48 is one commercially available method to manage respiratory motion. IMRT for lung cancer also shows significant promise.49–53 We describe the clinical implementation of respiratory-gated intensity modulated radiotherapy at Virginia Commonwealth University (VCU). It reflects our experience, and is intended as a ‘‘how to’’ guide for institutions developing respiratory-gated IMRT programs. This article is not a review of respiratory-gated IMRT, and for further information, readers are urged to consult the references listed and related works. Although not discussed further here, positron emission tomography (PET) scanning is an important part of the treatment planning process for non-small cell lung cancer.53 Gated and 4D PET/CT approaches are currently under development.54–56

At VCU, we treated our first respiratory-gated IMRT patient, verified with Monte Carlo dose calculation, in 2001. Since 2003, we have followed a policy of evaluating all lung cancer patients for their suitability for respiratory gating. In 2005, we have followed the proce-
dure shown schematically in Fig. 1. The respiratory-gating device is the Real-Time Position Management (RPM) system (Varian Medical Systems, Palo Alto, CA). The RPM system is connected to a GE Lightspeed 16-slice scanner (GE Medical Systems, Waukesha, WI) for retrospective 4D CT imaging, a PQ 5000 CT scanner (Philips Medical Systems, Cleveland, OH) for prospective gated CT imaging, and a 21EX linear accelerator (Varian Medical Systems). The Pinnacle (Philips Medical Systems, Milpitas, CA) system is used for treatment planning.

THE RELATIONSHIP BETWEEN RESPIRATORY MOTION AND TUMOR MOTION

It is important to note upfront that gating, as implemented at our institution, uses an external respiration signal, determined from optically tracking a marker typically placed between the umbilicus and xiphoid process. Thus, the respiration signal is the abdominal wall motion, while the quantity of interest is the tumor motion. In general, the respiratory signal, R at time t can be related to the tumor motion, T, from the following equation

\[ R(t) = I + M[T(t + \Delta \theta)] + \epsilon(t), \]

where I is the interfraction internal motion due to day-to-day anatomic changes, \( M \) is the motion ratio of the respiratory signal to the tumor, \( \Delta \theta \) is the phase difference (in units of time) between the respiratory signal and the tumor, and \( \epsilon(t) \) is an error term, which under ideal conditions is negligible.

The correlation between R and T has been quantified in several articles, which demonstrate very good correlation (0.99) to very poor correlation (0.39) with phase shifts of over 1 second observed.

Note that respiratory gating as a concept is not limited to its current implementation of the respiratory signal being based on the external motion of the patient, and the confidence and accuracy of respiratory-gated delivery will increase as the relationship between R and T improves.

PATIENT SELECTION

There are many factors that may contribute to a patient’s suitability for respiratory gating, such as lung function, age, oxygen dependency, tumor position, etc.; however, we do not exclude any patients a priori before the clinical evaluation.

The 3 main clinical decisions, as shown in Fig. 1 are:

1. Is there sufficient motion to warrant respiratory gating? A 5-mm threshold is used (based on the AAPM Task Group draft report).
2. Can clinical goals be fully achieved without respiratory gating?
3. Is the respiratory pattern sufficiently reproducible to make the use of gating worthwhile?

The first decision is made under fluoroscopy (note that tumor motion can also be observed with 4D CT; however, the number of breathing cycles that data is acquired for at any given location is typically 5–10 seconds for 4D CT and 20–30 seconds for fluoroscopy). The answer to the second question is difficult to quantify and depends on factors such as treatment intent (palliative vs. radical), tumor size, tumor stage, patient comorbidities, etc., and is evaluated on a case-by-case basis. The answer to the third question is also difficult to quantify; however, patients with breathing rates above 20 cycles per minute, or traces exhibiting significant baseline shift, are generally not good candidates for gating. Our approach is to try the gated imaging procedure. If unsuccessful, the fallback position is to treat without gating. In our experience, we have not yet had a patient who was successfully imaged with gating not be able to be treated with gating due to degraded respiratory reproducibility during treatment.

In our experience, over 80% of lung cancer patients have more than 5 mm of fluoroscopy-evident motion and their breathing is sufficiently reproducible to benefit from gating. We tend to be conservative and use gating, unless it is perceived that respiratory gating will have negligible impact on the clinical goals of the treatment (decision 2 above).

RESPIRATORY TRAINING

Recent studies have shown that visual and audio-visual biofeedback improves the respiratory reproducibility of lung cancer patients over the treatment...
Improved respiratory reproducibility affects both the accuracy and efficiency of respiratory gating, as well as improves the images used for treatment planning. Users are recommended to implement breathing training where possible.

**FLUOROSCOPY PROCEDURE**

A fluoroscopic evaluation of the patient serves three purposes:

1. To determine if the motion is significant enough to warrant gating (as described).
2. To observe the correlation between the tumor motion and respiratory surrogate motion and evaluate if there is a phase shift between the internal anatomic motion and the synchronously acquired respiratory signal. A detected phase shift can be corrected for by altering the gating window settings.
3. To observe respiratory reproducibility.

Example fluoroscopic images at inhale and exhale are shown in Fig. 2. A step-by-step fluoroscopy procedure guide is given in Appendix I.

**RESPIRATORY-GATED CT IMAGING**

At VCU, lung cancer patients are positioned supine on a wingboard with their arms raised above their head.

Accounting for respiratory motion during CT imaging can reduce motion artifacts observed on CT scans. As an example, images of static, respiratory-gated, and free breathing CT images for a lung phantom are shown in Fig. 3 (a comparison of respiratory-gated and free-breathing patient images can be found in Ref. 32). The motion phantom settings for a sinusoidal motion pattern were a 1-cm range of motion and 4-second motion period. For patients, the extent of the observed artifacts for the free-breathing scans will depend on the magnitude and period of motion as well as the CT scan acquisition parameters. If unaccounted for, motion artifacts occur in all imaging modalities, although may manifest them-
selves differently depending on the acquisition type. Detailed procedures for CT imaging for retrospective 4D CT imaging and prospective gated CT imaging are given in Appendices II and III, respectively.

RESPIRATORY-GATING IMRT TREATMENT PLANNING

A useful guide for the planning process of thoracic radiotherapy is given in Ref. 65. The first stage of treatment planning involves contouring, and it should be noted that this is perhaps the most error-prone step in the treatment process due to observer variability.65–70 Per RTOG guidelines,71 the GTV is defined as the tumor and regional lymph nodes greater than 1 cm in short axis. The GTV to CTV margin is 6 mm for squamous cell carcinoma and 8 mm for adenocarcinoma for tumors in the lung,72 and 5 mm in the mediastinum. The GTV-CTV expansion is edited such that it does not extend into the chest wall, mediastinum, or across lobe boundaries unless infiltrated by the tumor.50 The CTV to PTV margin is 8 mm to account for setup error, residual motion during the treatment gate, and day-to-day changes in tumor position with respect to the skeletal anatomy. Normal tissues contoured for IMRT planning are the esophagus, spinal cord (both expanded 5 mm for planning purposes),50 the lungs, heart, and planning normal tissue volume (entire thorax minus PTV).50

Fig. 3. (a) Lung IMRT phantom with a “tumor” outlined and implanted markers placed on a prototype motion platform (see Fig. 9) and coronal CT images acquired under (b) static, (c) gated, and (d) free-breathing conditions (1-cm range of motion).

Fig. 4. Respiratory-gated IMRT isodose plans calculated with (a) Superposition and (b) Monte Carlo. The 74-, 40-, and 20-Gy isodose levels are shown. The Monte Carlo calculations are used clinically at our institution as part of the quality assurance process for each IMRT patient, with the results recorded in the patient’s chart and reviewed by the patient’s physician.

Fig. 5. Respiratory-gated IMRT dose-volume histogram calculated with superposition (solid curves) and Monte Carlo (dashed curves).
Generally, 6 coplanar non-opposed predominantly anterior-posterior beams, e.g., gantry angles of 320°, 0°, 40°, 160°, 200°, 240° (or variants thereof depending on tumor location) are used. Note that for our linacs, a gantry angle of 0 means that the beam is pointing toward the floor.

Table 1 gives a list of dose volume constraints giving acceptable plans over a wide variety of tumor size and locations. As an example, 74 Gy in 37 fractions were prescribed to 95% of the PTV. This fractionation scheme was determined to be the maximum tolerated dose for concomitant chemotherapy in the RTOG 0117 study. Note that this clinical implementation differs from the RTOG 0117 trial in that IMRT and gating are utilized, a superposition convolution dose calculation algorithm with heterogeneity corrections is used for dose calculations and different GTV-CTV and CTV-PTV margins.

The superposition algorithm used for treatment planning, although a significant improvement over other algorithms historically used for planning, does not explicitly transport particles through the complex MLC geometry or in the patient. Thus, at VCU, we use Monte Carlo for verification of all IMRT treatments calculated with superposition and Monte Carlo algorithms are given in Fig. 4. Although for this case there is good general agreement, the Monte Carlo 74-Gy isodose curve is slightly smaller than that of the superposition curve, and a cold spot is observed near the bronchiole. The corresponding dose volume histograms are given in Fig. 5.

### PRETREATMENT PORTAL IMAGING

Respiratory motion affects the electronic portal image (EPI) verification for thoracic radiotherapy as the anatomy typically used for patient alignment (apart from the vertebral bodies) move with respiration, namely the chest wall, diaphragm, ribs, aortic knop, and carina. This motion causes 2 problems: (1) the anatomy imaged is not representative of its actual position during treatment; and (2) motion of the anatomy during the image acquisition process blurs the image, reducing contrast and diminishing the utility of the images. These problems can be mitigated by utilizing respiratory-gated EPI. Apart from the improvements made by respiratory gating during CT simulation (and hence more anatomically representative DRRs) and the potential for margin reduction during treatment planning, we can hypothesize that respiratory gated EPI: (1) reduces motion during imaging; and (2)

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**Table 1. Dose-volume constraints for respiratory gated IMRT treatment planning**

<table>
<thead>
<tr>
<th>Structure</th>
<th>Constraint Type</th>
<th>Dose (Gy)</th>
<th>% Volume</th>
<th>Weight</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>PTV</td>
<td>MinDVH</td>
<td>74.0</td>
<td>95</td>
<td>100</td>
<td>Prescription dose71</td>
</tr>
<tr>
<td>PTV</td>
<td>Min Dose</td>
<td>66.6</td>
<td>-</td>
<td>40</td>
<td>Based on Liu et al.50</td>
</tr>
<tr>
<td>PTV</td>
<td>Max Dose</td>
<td>88.8</td>
<td>-</td>
<td>40</td>
<td>Based on Liu et al.50</td>
</tr>
<tr>
<td>PTV</td>
<td>Min Dose</td>
<td>74.0</td>
<td>-</td>
<td>10</td>
<td>Soft constraint to obtain uniform PTV dose</td>
</tr>
<tr>
<td>PTV</td>
<td>Max Dose</td>
<td>74.0</td>
<td>-</td>
<td>10</td>
<td>Soft constraint to obtain uniform PTV dose</td>
</tr>
<tr>
<td>Heart</td>
<td>Max DVH</td>
<td>40.0</td>
<td>50</td>
<td>20</td>
<td>Reduce heart dose</td>
</tr>
<tr>
<td>Heart</td>
<td>Max DVH</td>
<td>40.0</td>
<td>25</td>
<td>1</td>
<td>Soft constraint to further reduce heart dose</td>
</tr>
<tr>
<td>Cord PRV</td>
<td>Max Dose</td>
<td>45.0</td>
<td>-</td>
<td>50</td>
<td>Upper limit on cord</td>
</tr>
<tr>
<td>Esophagus PRV</td>
<td>Max DVH</td>
<td>55.0</td>
<td>30</td>
<td>40</td>
<td>Reduce esophagus dose</td>
</tr>
<tr>
<td>Esophagus PRV</td>
<td>Max DVH</td>
<td>40.0</td>
<td>30</td>
<td>1</td>
<td>Soft constraint to further reduce esophagus dose</td>
</tr>
<tr>
<td>Lungs minus GTV</td>
<td>Max DVH</td>
<td>20.0</td>
<td>30</td>
<td>20</td>
<td>Reduce lung dose</td>
</tr>
<tr>
<td>Lungs minus GTV</td>
<td>Max DVH</td>
<td>20.0</td>
<td>15</td>
<td>1</td>
<td>Soft constraint to further reduce lung dose</td>
</tr>
<tr>
<td>Skin minus PTV</td>
<td>Max Dose</td>
<td>80.0</td>
<td>-</td>
<td>100</td>
<td>Reduce high dose areas to uncounted normal tissue outside PTV</td>
</tr>
</tbody>
</table>

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Fig. 6. (a) Static and (b) dynamic images of the PIPSpro QC-3 image quality device on a prototype motion platform (see Fig. 9).
increases contrast and thus allow better visualization and use of images. Together these 2 advances result in improved tumor-beam targeting during radiotherapy.

The effect of the 2 hypotheses are demonstrated using the PIPSpro QC-3 phantom (Standard Imaging) placed on a motion platform prototype (Standard Imaging) with a 2-cm amplitude of motion and a 3.5-second period of motion. Examples of images without and with motion are shown in Fig. 6a and Fig. 6b, respectively. Clearly, the motion blurring in the right image is evident. The image quality was too poor for the PIPSpro software to determine the contrast-to-noise ratio on the moving image.

An example of a pretreatment gated patient EPI image acquired at exhale is shown in Fig. 7. Note that the tumor is visible in this image; however, if the image had been acquired during mid-inhalation or mid-exhalation, the tumor image would be blurred, thus reducing contrast and potentially leading to a geometric error due to misalignment.

RESPIRATORY-GATING IMRT DELIVERY

Respiratory gating changes a continuous delivery to a periodic delivery, as the beam is off when the patient’s respiratory pattern is not within the preset gating window. Thus, the treatment time increases and the periodic nature can affect beam output. With IMRT, the treatment time increases over conventional delivery. Gating combined with IMRT increases the treatment time by approximately 2 minutes in our experience, although this will be affected by the duty cycle used, treatment dose rate, and leaf sequencing algorithms. A treatment sequence for respiratory gated DMLC IMRT is shown in Fig. 8. Detailed instructions for respiratory-gated delivery are described in Appendix IV.

PROCEDURAL ISSUES

Not all record-and-verify (R/V) systems integrate with respiratory gating devices. Treating without gating as part of the R/V system can result in multiple error scenarios including (1) ignoring gating when gating was prescribed; (2) applying gating when not prescribed; and (3) treating a patient with another patient’s gating treatment settings. Instruction of, and communication between, the simulation, planning, and treatment teams is an important part of reducing delivery errors.

POSITIONAL QUALITY ASSURANCE

As respiratory gating is by nature accounting for positional change, positional quality assurance is important. Performing a system positional check is recommended. This involves gated CT imaging of a motion phantom, from which digitally-reconstructed radiographs (DRRs) are created. The phantom is then setup on the treatment unit, from which gated portal images are acquired. The comparison of the DRRs with the gated treatment images yields an estimate of the geometric uncertainty under ideal conditions. For patient cases,
margins for microscopic spread, set-up error, and internal motion should be added.

**DOSIMETRIC QUALITY ASSURANCE**

Several publications have described dosimetric quality assurance methods that can be used for respiratory gating. \(^{31,40,46-48,73}\) To ensure that the linear accelerator output is stable when the beam is turned on and off during gated delivery, experiments should be performed to ensure, that in the absence of detector motion, the machine output with and without gating are similar. Measurements with the detector in motion for gated and free breathing situations give estimates of the benefits of gating over not accounting for motion.

Using the phantom on the motion platform shown in Fig. 9, ionization measurements were performed using the IMRT fields. The results are given in Table 2, which shows that the output of a respiratory-gated IMRT beam is similar to that of an ungated IMRT beam, and also that if the beam is not gated and there is motion, the results start to significantly deviate from the planned delivery.

Film dosimetry for a gated IMRT patient is shown in Fig. 10 for static, gated, and free breathing cases. The magnitude of the dosimetric difference between the static delivery are smaller for the gated delivery than for the free breathing delivery. We perform film dosimetry for all of our IMRT patients (gated or otherwise), but not for gated non-IMRT patients.

**SUMMARY**

Respiratory-gated IMRT is a complex procedure requiring understanding of the process, intradepartmental communication during the planning and delivery processes and quality assurance measures at several steps of

<table>
<thead>
<tr>
<th>Phantom Moving?</th>
<th>Beam Gated?</th>
<th>Relative Dose</th>
<th>% Reproducibility (1σ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>No</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>No</td>
<td>Yes</td>
<td>0.99</td>
<td>0.4</td>
</tr>
<tr>
<td>Yes</td>
<td>Yes</td>
<td>1.01</td>
<td>0.4</td>
</tr>
<tr>
<td>Yes</td>
<td>No</td>
<td>1.03</td>
<td>1.2</td>
</tr>
</tbody>
</table>

Dose values are relative to dose measured for a static beam to a static phantom.

![Fig. 9. The lung IMRT phantom and motion platform used for the positional and dosimetric quality assurance. The ionization chamber and film positions are shown.](image1)

![Fig. 10. An isodose comparison of static delivery (dashed lines in all figures) with (a) respiratory-gated delivery and (b) free-breathing delivery. The standard deviation of the dosimetric difference from the static delivery was 2.2% for the gated delivery and 4.3% for the free-breathing delivery.](image2)
the radiotherapy procedure. If carefully implemented, the potential benefits of both of these modalities can be combined to lead to an anticipated improvement of therapeutic outcome.

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Medical Dosimetry

Volume 31, Number 2, 2006


59. Tsunashima, Y.; Sakae, T.; Shioyama, Y.; et al. Correlation between the respiratory waveform measured using a respiratory sen-
3. Click on Add Treatment Field (Name it as Fluoro NOT for Treatment)
4. By default, the system starts tracking. Verify grayed out “Track” button.
5. After learning motion extents, the RPM system should start recording motion. If recording does not start automatically:
   ● Check to see if a marker block has been placed on patient’s abdomen.
   ● Check to see that both markers are visible on RPM image window and are within the field of view for entire breathing cycle.
   ● Click on Stop and Track again and if necessary, click on the Record button.

**During imaging: At fluoroscope**
1. Adjust CT C-Arm position until tumor is approximately in the center of the display.
2. Press and Hold Fluoro Foot Pedal for 30 seconds.
3. Release Foot Pedal to Stop acquisition.

**During imaging: At RPM Respiratory gating system console**
1. Click Save on the RPM system menu bar.
2. Evaluate motion of anatomy of interest using the playback tools provided in the RPM system.
   Use anatomic landmarks to estimate motion magnitude. Evaluate correlation between external respiratory motion and internal motion.

**APPENDIX II. RETROSPECTIVE 4D CT IMAGING**

**PROCEDURE DOCUMENTATION**

**Equipment**
1. Plastic infra-red reflective marker block.
2. Patient immobilization devices.
3. Ball bearings (BBs).

**Before start of imaging study**
1. Remove camera assembly from the wall and mount RPM camera assembly onto the CT couch. Note that the camera only attaches to the flat couch, which is required for radiotherapy.
2. Add BBs to patient on skin marks.
3. Check patient entry into bore and mark maximum extent of wingboard into PET bore—collision a potential issue.

**Before imaging: at RPM respiratory gating system console**
1. Add patient name.
2. Click on Add Treatment Field (Name it as CT Use for Treatment).
3. Click Select.
4. Click “Yes” when prompted to set this field as a reference field.
5. Adjust gating thresholds by moving the semi-circular bar on the left hand side of the chart window. Typically, we use 30–70% phase range to image at exhale.
6. Just before x-ray on (Start) then hit record on RPM—only gives 6 minutes of recording time; therefore, restart before imaging.

**Imaging: at Discovery LS console**
1. Insert patient name- format LastName*FirstName.
2. Select Resp Gating protocol.
3. Acquire AP and Lateral scouts.
4. Ensure patient is aligned.
5. Ensure BBs are marked.
6. Insert cine duration = Breathing period from RPM + 1.0 seconds (round up).
7. From tab Thickness/Speed update Cine time between images = Breathing period/10 (round down).

**After imaging: at RPM respiratory gating system console**
1. Click on Stop.
2. Add exam number and series number from CT scanner.
3. Click on Save.
4. Click on “Yes” when prompted to save data as new session.
5. Close RPM interface.

**After imaging: at advantage 4D CT workstation**
1. Select patient, and axial series.
2. Start advantage 4D.
3. Check that default selected RPM file by id numbers (default should be correct but always check).
4. In 4D review add series number “300”.
5. Align X to tumor Centroid.
6. Right click to assess motion in movie.
7. Cursor on phase % — step through phases with left/right arrow keys.
8. Choose phases to use for treatment plan.
9. IMPT: Phase(s) sent to Pinnacle should match those from RPM session.
10. In export, click on MIP and Average-label MIP series 200.
11. If desired, can contour in Fusion.
12. If desired, need to convert contours to DICOM in Advantage sim, output→ save plan.
13. In series, select images to send to treatment planning system.

**APPENDIX III. PROSPECTIVE GATED CT IMAGING**

**PROCEDURE DOCUMENTATION**

**Before imaging: at RPM respiratory gating system console**
1. Switch cable connections to enable CT Simulation.
2. Select current patient name.
3. Click on Add Treatment Field (Name it as CT Use for Treatment).
4. Click Select.
5. Click “Yes” when prompted to set this field as a reference field.
6. By default, the system starts tracking. Verify grayed out “Track” button.
7. After learning motion extents, the RPM system should start recording motion. If recording does not start automatically:
   ● Check to see if a marker block has been placed on patient’s abdomen.
   ● Check to see that both markers are visible on RPM image window and are within the field of view for entire breathing cycle.
8. Click on Stop and Track again and if necessary, click on the Record button.
9. Click on Enable Gating.
10. Adjust gating thresholds by moving the semi-circular bar on the left hand side of the chart window (green shade should fall around exhale portion of the respiratory motion trace).
11. Confirm with therapist that RPM system is setup for gated CT scan acquisition.
12. Perform gated CT scan.

**During Imaging: at PQ 5000 CT console**
1. Select protocol and take pilot. The appropriate protocol should be selected from the axial protocols, which are displayed when Spiral Onc is not highlighted.
2. Ensure slice thickness and index are set to 3 mm.
3. Select scan limits and save.
4. Under Select Scanning Mode, check that Axial, Multi, Load’N’Go, and ADS are highlighted.
5. In System Setup, turn Injector to On.
6. Check that ELTP displays Injector On above Help.
9. Before starting scan wait and ask patient to relax, and breathe normally. Explain that there will be intermittent noise (this noise is the beam on/off and has been observed to disturb patient breathing patterns), and that the couch will also periodically move.
10. Push CT scanner START button.
11. Note that the first scan is not necessarily synchronized with the respiratory signal. Furthermore, should the scanner time out for any reason, the injector port will need to be turned on again, and the first scan after restarting will not necessarily be synchronized with the respiratory signal.
12. Observe that the triggering of the CT scanner occurs at the “CT delay value” before the breathing trace enters the gating limits, and that the CT scanner slice acquisition begins as the breathing trace enters the gating limits. Allow some tolerance if the patient cycle-to-cycle breathing reproducibility is poor.
13. When the scan is complete, put the CT scanner back in spiral mode for the next CT simulation.

APPENDIX IV. GATED TREATMENT DELIVERY PROCEDURE DOCUMENTATION—TREATMENT SESSION

In treatment room
1. Check that Marker Block has correct patient name.
2. Place Marker Block on patient’s chest with silver dots facing camera. The sagittal laser should not cover the silver dots.

In console room
1. On Gating Board, turn key to Gating Enabled.
2. Start Gating program (Gating).
3. Select Patient.
4. Select Session.
5. Hit Stop.
6. Hit Track and wait until the periodicity indicator falls to half or less of the meter (this may occur automatically). If tracking does not occur, either obscure reflective surfaces seen on the camera (e.g., belt, watch, etc.) and/or dim the treatment room lights.
7. Hit Record. Ensure that part on breathing trace is within gating window.
8. Hit Enable Gating on Gating Computer.
10. Increase treatment time by ~4.
11. Increase dose rate to 600.
12. Turn key ON (Linac console) and hit the Beam ON button. Note: for EPID images, the Beam On button should be depressed when the patient’s breathing trace starts to enter the gating window, otherwise, an interlock will occur.
13. Treat next beams.
14. Hit STOP.
15. Exit. (Do not save data as a new session.)
16. Log out of Gating Computer.
17. Turn key on Gating Board to Gating Disable.

In treatment room
1. Place Marker Block in bag for subsequent sessions.