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Deep-inspiration breath-hold kilovoltage cone-beam CT for setup of stereotactic body radiation therapy for lung tumors: Initial experience

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Summary We report our initial experience with deep-inspiration breath-hold (DIBH) cone-beam CT (CBCT) on the treatment table, using the kilovoltage imager integrated into our linear accelerator, for setting up patients for DIBH stereotactic body radiation therapy (SBRT) for lung tumors. Nine patients with non-small cell lung cancer (seven stage I), were given 60 Gy in three fractions. All nine patients could perform a DIBH for 35 s. For each patient we used a diagnostic reference CT volume image acquired during a DIBH to design an SBRT plan consisting of 7—10 noncoplanar conformal beams. Four patients were setup by registering DIBH kilovoltage projection radiographs or megavoltage portal images on the treatment table to digitally reconstructed radiographs from the reference CT. Each of the last 14 fractions out of a total of 27 was setup by acquiring a CBCT volume image on the treatment table in three breath-holds. The CBCT and reference CT volume images were directly registered and the shift was calculated from the registration. The CBCT volume images contained excellent detail on soft tissue and bony anatomy for matching to the reference CT. Most importantly, the tumor was always clearly visible in the CBCT images, even when it was difficult or impossible to see in the radiographs or portal images. The accuracy of the CBCT method was confirmed by DIBH megavoltage portal imaging and each treatment beam was delivered during a DIBH. CBCT acquisition typically required five more minutes than radiograph acquisition but the overall setup time was often shorter using CBCT because repeat imaging was minimized. We conclude that for setting up SBRT treatments of lung tumors, DIBH CBCT is feasible, fast and may result in less variation among observers than using bony anatomy in orthogonal radiographs.

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1. Introduction

Several phase I studies of stereotactic body radiation therapy (SBRT) for lung tumors have now been completed [1—6] and phase II trials are under way [7—10]. The results available suggest that local control is achieved as long as the dose is high enough. SBRT for lung tumors requires respiratory control so that tumor margins can be reduced enough that the treatment can be tolerated.

The Radiation Therapy Oncology Group (RTOG) is now conducting a phase II study (RTOG 0236) to rigorously evaluate the efficacy of a protocol that calls for three 20 Gy fractions (approximately 2—8 days apart) [10]. Our patients were treated in accordance with this protocol except that respiratory control was achieved by a breath-hold technique, which is not allowed by that protocol. However, a variety of tumors have been successfully treated with similar deep-inspiration breath-hold (DIBH) techniques [3,5,11—17]. For lung treatments, DIBH techniques can reduce the volume of normal lung treated [14,18].

Patient setup for SBRT must be more accurate than in conventional lung treatments, and imaging on the treatment table with respiratory control is highly desirable, if not essential, for this purpose. Our institution's initial experience with DIBH cone-beam CT (CBCT), using a kilovoltage imager integrated into a linear accelerator (varian trilogy with on-board imager), for setting up SBRT for lung tumors shows that it is feasible and suggests that it may lead to less variation among observers than projection radiography (either gated or breath-hold) on the treatment table. Though a very similar technique has been used with a CT-on-rails in the treatment room [5,19—22], we believe this is the first report of the use of DIBH CBCT to position patients for SBRT for lung tumors.

CBCT on the treatment table is a recent development that builds on the introduction of kilovoltage (kV) projection radiography on the treatment table [23—29]. The latter, in turn, was made possible by the development of high-quality flat panel detectors for digital radiography [24,30—32]. Kilovoltage images show bony anatomy much better than megavoltage images and may therefore be better for setting up patients for treatment of some sites. Megavoltage images are still important for verifying treatment ports.

CBCT on the treatment table has two advantages over kV projection radiography for patient setup. In lateral projections, even with the best technique, the bony anatomy is often difficult to see but it is always easily seen on a CBCT. The CBCT is three-dimensional so there is far more information for registering the CBCT with the planning CT than there is for matching a pair of orthogonal projections to digitally reconstructed radiographs (DRRs) from the planning CT. Compared to megavoltage CBCT, a higher contrast-to-noise ratio for the same dose can be achieved with kilovoltage CBCT [33].

Since a projection radiograph can be acquired in a few seconds, any of the established respiratory control techniques, including gating, are effective. CBCT, on the other hand, is slow; a 360° CBCT acquisition requires one minute, because safety regulations limit gantry rotation speed. However, a 360° CBCT acquisition can be done in three 30-s breath-holds. The scan is interrupted just before the end of the first and second breath-holds and resumed just before the start of the second and third breath-holds, as described below. This has previously been done for setting up treatments of liver tumors [13].

Table 1 Patient characteristics

Total number of cases	9
Age (years)	
Median	74
Range	66—91
Gender	
Male	6
Female	3
Histology	
Non-small cell lung cancer	9
Stage	
I	7
II	1
IV	1
Tumor diameter (mm)	
Median	29
Range	12—44

Characteristics of lung cancer patients treated with deep-inspiration breath-hold stereotactic body radiation therapy.

In the following sections we describe patient selection and the entire process of imaging, planning, setting up, and treating the patient, using the DIBH technique to minimize respiratory motion. We hope to convince the reader that DIBH CBCT is fast enough to be practical and enables the observer to place the isocenter reliably in the tumor, even when the patient setup on the treatment table does not perfectly match the reference CT setup, so that it is difficult to use bony anatomy alone, or when the tumor is difficult or impossible to see in kilovoltage projection radiographs or megavoltage portal images.

2. Methods and materials

2.1. Patient selection

All nine patients selected for breath-hold treatment had non-small-cell lung cancer (NSCLC) (Table 1); all but one had a tumor in an upper lobe. The ability of the patient to hold his or her breath for at least 35 s is essential and this is checked at the beginning of the planning process as described below. All of the patients selected but one (who had a stage IV NSCLC) were also chosen in accordance with RTOG Protocol 0236 [10], which effectively eliminates those whose tumor is within 2 cm of a major bronchus. Two other patients who met all the criteria in RTOG 0236 were eliminated because they could not perform a long enough DIBH.

2.2. Initial simulation

Each patient was first immobilized using a custom mold and setup in a conventional simulator with the isocenter in the tumor. The tumor was observed for several breathing cycles