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Clinical Investigation

Prospective Evaluation of Dual-Energy Imaging in Patients Undergoing Image Guided Radiation Therapy for Lung Cancer: Initial Clinical Results

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Summary

A prospective feasibility study was conducted to compare dual-energy (DE) imaging to conventional x-ray imaging in terms of tumor visibility for patients undergoing kV-based image guided radiation therapy for lung cancer. DE subtraction resulted in complete suppression of overlying bone in all DE images analyzed. DE imaging resulted in improvement by an average factor of 4.7 compared to 120-kVp x-rays without increasing image acquisition dose to the skin.

Purpose: A prospective feasibility study was conducted to investigate the utility of dual-energy (DE) imaging compared to conventional x-ray imaging for patients undergoing kV-based image guided radiation therapy (IGRT) for lung cancer.

Methods and Materials: An institutional review board-approved feasibility study enrolled patients with lung cancer undergoing IGRT and was initiated in September 2011. During daily setup, 2 sequential respiration-gated x-ray images were obtained using an on-board imager. Imaging was composed of 1 standard x-ray image at 120 kVp (1 mAs) and a second image obtained at 60 kVp (4 mAs). Weighted logarithmic subtraction of the 2 images was performed offline to create a soft tissue-selective DE image. Conventional and DE images were evaluated by measuring relative contrast and contrast-to-noise ratios (CNR) and also by comparing spatial localization, using both approaches. Imaging dose was assessed using a calibrated ion chamber.

Results: To date, 10 patients with stage IA to IIIA lung cancer were enrolled and 57 DE images were analyzed. DE subtraction resulted in complete suppression of overlying bone in all 57 DE images, with an average improvement in relative contrast of 4.7 $\pm$ 3.3 over that of 120 kVp x-ray images ($P<.0002$). The improvement in relative contrast with DE imaging was seen for both smaller (gross tumor volume [GTV] $\leq$5 cc) and larger tumors (GTV >5 cc), with average relative contrast improvement ratios of 3.4 $\pm$ 4.1 and 5.4 $\pm$ 3.6, respectively. Moreover, the GTV was reliably localized in 95% of the DE images versus 74% of the single energy (SE images, ($P=.004$). Mean skin dose per DE image set was 0.44 $\pm$ 0.03 mGy versus 0.43 $\pm$ 0.03 mGy, using conventional kV imaging parameters.

Conclusions: Initial results of this feasibility study suggest that DE thoracic imaging may enhance tumor localization in lung cancer patients receiving kV-based IGRT without increasing imaging dose. © 2014 Elsevier Inc.

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Introduction

Dual energy (DE) subtraction radiography is a diagnostic imaging technique that enhances the detection of thoracic abnormalities observed on anterior chest radiographs. First used clinically in 1986, DE imaging has the advantage of improving the detection and diagnosis of soft tissue abnormalities in the chest, including lung tumors, using widely available kilovoltage (kV) x-ray technology (1-9).

The DE technique takes advantage of the higher differential attenuation of bone as a function of energy relative to that of soft tissue to generate tissue-selective x-ray images. Two sequential radiographs are obtained, 1 at a low energy (LE; ie, 60 kVp) and 1 at a high energy (HE; ie, 120 kVp). Weighted logarithmic subtraction of the images is performed to create a third image that highlights soft tissue. In the thorax, where tumors are often obscured by overlying bony structures, DE imaging has the potential to improve tumor definition by selectively subtracting the ribs. While used commonly in diagnostic radiology, DE imaging has not been studied clinically in a therapeutic radiation setting.

Applying DE imaging to conformal radiation therapy techniques would be useful if it could improve tumor localization throughout respiration without relying on fiducial markers. This is especially important when treating with hypofractionation, which increases the need for accurate tumor localization. While cone beam computed tomography (CBCT) has proven successful in image guided radiation therapy (IGRT), slow acquisition time and tumor motion during acquisition are major disadvantages of this technique. Planar kV-based IGRT has become widely used owing to the improved visibility of bony anatomy compared to that of megavoltage (MV) portal imaging, and it confers the added benefit of decreasing image acquisition dose and time compared to CBCT. Although kV imaging accomplishes the need to discern bony anatomy, conventional kV x-ray images lack meaningful soft tissue definition. DE imaging offers a potential solution that takes advantage of the widely accessible, relatively inexpensive kV-image guidance systems to achieve improved soft tissue visibility while minimizing both acquisition time and patient imaging dose.

In this study, we investigated the hypothesis that DE subtraction imaging would enhance tumor visibility compared to conventional x-ray imaging for patients with lung cancer treated with kV-based IGRT. A prospective feasibility study was initiated in 2011 to test this hypothesis, and the initial results are reported here.

Methods and Materials

Study design, consent process, and data collection and analysis for this prospective feasibility study were approved by our institutional review board. This study was initiated in September 2011 and is ongoing.

Patients and treatment

Ten patients (with a total of 11 tumors) treated with curative intent radiation therapy for lung cancer were enrolled from September 2011 to April 2013 at our institution. Eligibility criteria included patients with nonmetastatic lung cancer and a Karnofsky performance status (KPS) of 70 or greater, who were referred for IGRT. Exclusion criteria included patients with metastatic disease, patients unable to tolerate respiration gating, and patients with a KPS of <70. Table 1 shows patient and tumor characteristics.

Simulation and treatment planning

Patients underwent CT simulation and RT planning according to our standard institutional protocol. All patients underwent simulation imaging in the supine position and were immobilized using an alpha cradle (Smithers Medical Products, Inc., Canton, OH) indexed to the treatment table. A 4-dimensional (4D) CT simulation was performed using the Real-Time Position Management (RPM) system (Varian Medical Systems, Palo Alto, CA) on a dedicated CT scanner (Brilliance large bore; Philips Medical Systems, Andover, MA). The gross tumor volume (GTV) was contoured on the free-breathing, zero phase, 50% phase, and maximum intensity projection series. Summation of the four GTVs was performed to create an internal target volume (ITV). A clinical target volume (CTV) margin of 0.7 cm was added to the ITV for the 3DCRT cases. A planning target volume (PTV) margin of 0.5 cm was added to the ITV for the SBRT cases and to the CTV for the 3DCRT cases. The prescription dose and technique were determined by the treating radiation oncologist. Table 2

Table 1 Patient and tumor characteristics

Characteristic	No. of tumors
Sex	
Male	4
Female	7
Age	
≤70 yrs	3
>70 yrs	8
KPS	
70	3
80	6
90	2
Laterality	
Left	6
Right	5
GTV volume	
≤5 cc	5
>5 cc	6

Abbreviations: GTV = gross tumor volume; KPS = Karnofsky performance status.