

# Quantitative Diffusion-Weighted MR Imaging of Lung Neoplasm: A Promising Method for Delineating Active Tumor

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## Target audience

Medical physicists, radiologists, radiation oncologists, and caregivers involved in treatment of lung cancer.

## Purpose

Lung cancer remains the most deadly of all cancers in the United States<sup>1</sup>. Radiation therapy of lung cancer potentially leads to normal tissue injury, such as radiation pneumonitis and fibrosis. Factors that determine the probability and severity of injury following thoracic radiation include the dose as well as the volume of organ irradiated<sup>2</sup>. Over the course of treatment, the tumor shrinks and the extent of tumor cells changes. Image-guided adaptive treatment methods that can achieve high dose to the remaining viable tumor cells while sparing normal tissue would improve clinical therapeutic ratio. Obstacles to MR imaging in the lung include scarcity of tissue to generate a measurable signal and poor spatial resolution due to respiratory motion. The purpose of this work is to develop a clinically useful diffusion-weighted MR imaging method amenable to lung tumor imaging, which affords quantitative apparent diffusion coefficients (ADCs) that can reliably identify and delineate viable tumor.

## Methods

**Pulse Sequence:** A respiratory-gated echo-planar diffusion-weighted pulse sequence was implemented on a 1.5T Siemens Avanto MRI scanner. Pulse sequence parameters are: TR ≈ 4500, TE = 73, number of signal averages = 2, fat saturation on, field of view = 379x284mm, matrix = 192x108 pixels, slice thickness = 4-6mm, 7 axial slices. Both phantom and *in vivo* studies utilized the body transmit coil and the 8-channel body array matrix receive coil. Diffusion gradients were applied to all three axes producing trace-weighted images with eight b-values ranging from 0-1000 μs/μm<sup>2</sup>.

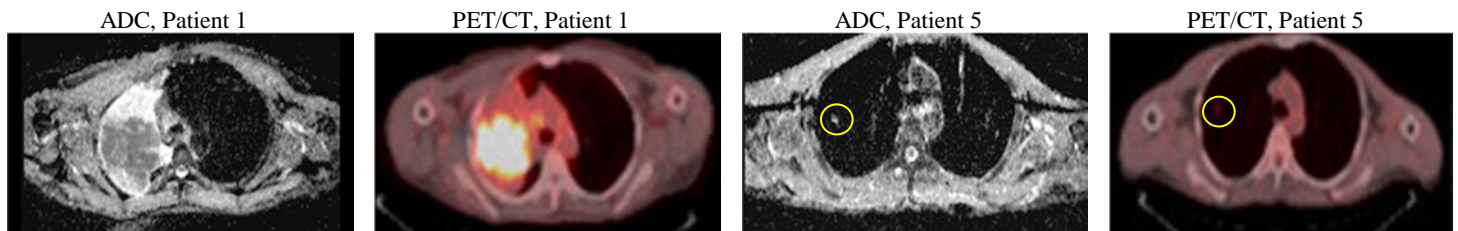
**Phantom study:** Four 10 ml test tubes filled with water, acetone, ethanol, and corn oil, were placed near the magnet isocenter, and diffusion-weighted images were acquired. Small (7x7pixels) regions of interest (ROIs) were placed in each phantom in each of seven slices for every b-value, and the mean signal was recorded. Average ADC in ROIs were calculated in the usual way as the slope of the ln(signal) versus b-value decay curve.

**In vivo study:** Repeatability was investigated by conducting 25 diffusion studies in seven lung cancer patients who had also undergone PET/CT. Respiratory navigation was employed. An ROI with a 10mm radius was defined in the center of the tumor for each patient and spanning 3-5 axial slices. Similarly, ROIs were defined for cerebral spinal fluid (CSF) and spinal cord with a 2mm radius over 3 slices. ADC maps were generated using all b-values, and the mean ADCs in ROIs were recorded.

## Results

**Phantom study:** The measured ADC of water at room temperature (2.1 μm<sup>2</sup>/ms) agrees with the literature<sup>3</sup>, as do ADCs for acetone (4.1 μm<sup>2</sup>/ms) and ethanol (0.9 μm<sup>2</sup>/ms)<sup>4</sup>. Log of MR signal vs. b-value demonstrated a linear decay with Pearson correlation coefficients > 0.995. Fat saturation completely eliminated signal from the corn oil phantom.

**In vivo study:** Lung tumors were clearly visualized on ADC maps and matched well to positive areas on PET images (see Figure). Mean and coefficient of variation (CV) of ADC in tissue ROIs over all scans for N=7 patients are shown in the Table below. Inter-patient CV reflects inter-patient variation as well as day-to-day variation. Intra-patient CV in six patients that had multiple scans (2-3 scans/patient) was lower: 2-4% for CSF and cord and 4-8% for tumor. Higher CV in tumor compared to CSF and cord presumably reflects greater tissue microstructural heterogeneity.



ADC images provide clear visualization of lung tumor; hypointense ADC corresponds to PET positive regions.

## Conclusion

The method provides delineation of viable lung tumor and discrimination from normal and abnormal non-cancerous tissue. The remarkable precision of quantitative ADC using this pulse sequence will afford the ability to detect ADC changes in response to treatment and provide meaningful correlation with biological tissue state. Future work will include determination of optimal b-values for *in vivo* ADC measurements, and spatial correlation of quantitative ADC with PET uptake as well as with histology.

| ADC Values                 | CSF                      | Spinal Cord              | Lung Tumor               |
|----------------------------|--------------------------|--------------------------|--------------------------|
| Mean (25 scans total, N=7) | 2.47 μm <sup>2</sup> /ms | 1.02 μm <sup>2</sup> /ms | 1.34 μm <sup>2</sup> /ms |
| CV (inter-patient)         | 18%                      | 13%                      | 20%                      |
| CV (intra-patient)         | 3%                       | 2-4%                     | *4-8%                    |

\* scans on same day

## References

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