BRIEF REPORT

Practical Assessment of Bronchoscopically Inserted Fiducial Markers for Image Guidance in Stereotactic Lung Radiotherapy

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ABSTRACT

Introduction: Stereotactic radiotherapy is a high-dose precision technique necessitating accurate target visualization through either cone beam computed tomography (CBCT) or planar imaging with implanted fiducial markers. We have investigated the properties for image guidance using fiducial markers implanted through minimally invasive bronchoscopy.

Methods: Two fiducial marker types were implanted endobronchially in 10 patients undergoing radical radiation treatment for non–small cell lung cancer (eight using Visicoil linear fiducial markers [IBA Dosimetry GmbH, Schwarzenbruck Germany] and two using superDimension and superLock two-band markers [Covidien Inc., Minneapolis, MN]). Patients underwent four-dimensional computed tomography imaging for treatment planning and after completion of treatment to investigate marker movement. As part of the image guidance assessment, megavolt electronic portal images (EPIs) were acquired in addition to kilovolt planar and CBCT (Varian Medical Systems, Palo Alto, CA) images.

Results: In two of 10 patients (both receiving Visicoil markers), marker migration was observed before treatment. In patients with stable markers, both types were clearly visible in planar kilovolt imaging; however, in EPIs the markers could be detected only in selected beam directions in which bony interference was minimal. Diagnostic computed tomography scanning was able to demonstrate the markers with clarity, but significant starring artifacts were observed in CBCT. This was particularly problematic in patients with some lateral component of tumor motion during breathing.

Conclusions: The potential for fiducial migration must be considered and investigated if bronchoscopic implantation of fiducial markers is performed. The choice of marker is a compromise between trying to minimize CBCT artifacts while enabling visualization in EPI imaging, which is an ideal tool to verify gated radiotherapy delivery.

Keywords: Fiducial; Endobronchial; Image guidance; SBRT; SABR; EBUS

Introduction

Image guidance of radiotherapy in lung tumors is challenging because of both respiratory and cardiac induced motion. These motion-induced uncertainties result in an increased risk for geographic tumor miss and consequent potential of reduced tumor control. Fiducial markers have been investigated both as a

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surrogate of tumor position and to inform tumor motion in this context. However, fiducial markers are typically inserted using percutaneous techniques that are associated with the potential for significant toxicities. These include a pneumothorax rate that ranges from 13% to more than 60%.[1–3] Subsequent hospital admission and intercostal drain tube insertion to manage this complication is required in 3% to 44% of cases,[1,3–5] whereas this severity of complication is not reported in any studies describing endobronchial fiducial insertion.[6–9] Bronchoscopy offers an appealing alternative to percutaneous fiducial marker insertion given its superior safety profile. Our group has previously reported bronchoscopic implantation of gold fiducials using radial probe endobronchial ultrasound with virtual bronchoscopy and fluoroscopic or electromagnetic navigation guidance to achieve tumor localization and placement within/adjacent to peripheral lung tumors. Importantly, no procedural complications were sustained.[7]

In this study, we investigated the utility of bronchoscopically implanted fiducial markers for radiotherapy image guidance. In particular, we focused on the imaging implications of the composition of the fiducials, impact of geometric alignment with the tumor, and the capacity to visualize these fiducials using onboard imaging techniques.

Materials and Methods

This study was designed to assess the feasibility of improved image guidance by noninvasive implantation of fiducial markers in patients receiving radical radiotherapy for lung cancer.

Fiducials

In this ethics board–approved prospective study two types of fiducial markers were implanted endobronchially in 10 patients undergoing radical radiation treatment for non–small cell lung cancer. Eight patients received a single Visicoil (IBA Dosimetry GmbH, Schwarzenbruck Germany) linear fiducial 10 × 0.75-mm marker. Two were implanted with superDimension and superLock (Covidien Inc., Minneapolis, MN) two-band 13 × 0.9-mm markers (one receiving two markers to assess volumetric definition capabilities). The bronchoscopic implantation was performed under conscious sedation as previously described[10] using radial probe endobronchial ultrasound[11,12] and fluoroscopic guidance to achieve tumor localization and placement within or adjacent to peripheral lung tumors.

Radiographic Imaging

Patients had a time-resolved, 10-phase four-dimensional (4D) computed tomography (CT) scan (using the Philips Brilliance Big Bore system with bellows [Philips Healthcare, DA Best, the Netherlands]) for treatment planning and after completion of treatment to investigate marker movement. On the 4D series, mean breathing rate and motion range in each orthogonal plane were recorded using fiducial location. One patient's therapy was planned with only a three-dimensional positron emission tomography/CT image series with no time-resolved imaging. Onboard planar kilovoltage images were acquired for lateral and anterior-posterior views during patient setup for treatment. Cone beam CT (CBCT) scans were recorded for each fraction for stereotactic ablative body radiotherapy and used to validate patient positioning. During treatment delivery cine electronic portal imaging (EPI) series were acquired for selected gantry angles in six of the patients.

Results

Fiducial Placement

Fiducial markers were implanted as previously described[7] in all 10 patients without complication. In two of the eight patients implanted with Visicoil markers, migration or complete loss was observed in the period between insertion and first fraction of treatment delivery (identified on imaging at days 10 and 13 after placement, respectively). This time line of displacement is consistent with previous reports identifying migration during or immediately after insertion.[5] No positional change was observable in the two patients receiving superDimension-type fiducials. In those with stable fiducial markers, good correspondence between positioning on planning CT and treatment CBCT was noted (see Fig. 1). All patients with stable markers at the time of treatment had persistent fiducial location on follow-up (6–18 months after radiotherapy).

Radiographic Imaging

Markers were clearly visualized on all 10 phases of the planning 4D CT image series. The averaged three-dimensional volume (as used for planning) displayed the effect of motion primarily along the inferior-superior axis.

Imaging with 4D CT included assessment of patient motion ranges in each orthogonal plane. Both fiducial types were clearly visualized in each of the 10 gated breathing phases. Tumor motion ranged from 2 to 16 mm and was predominantly along the superior-inferior axis (Table 1). Median breathing rate was 16 breaths per minute (range 12–26). Visualization of fiducial markers was not influenced by breathing rate either on 4D CT or with onboard imaging.

Both marker types displayed characteristic metal streak artifacts on CBCT imaging. When combined with the effects of motion averaging during the cone beam acquisition, 2 to 3 mm of spatial uncertainty was