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PHYSICS CONTRIBUTION

CLINICAL FEASIBILITY OF USING AN EPID IN *CINE* MODE FOR IMAGE-GUIDED VERIFICATION OF STEREOTACTIC BODY RADIOTHERAPY

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Purpose: To introduce a novel method for monitoring tumor location during stereotactic body radiotherapy (SBRT) while the treatment beam is on by using a conventional electronic portal imaging device (EPID).
Methods and Materials: In our clinic, selected patients were treated under a phase I institutional review board–approved SBRT protocol for limited hepatic metastases from solid tumors. Before treatment planning multiple gold fiducial markers were implanted on the periphery of the tumor. During treatment the EPID was used in *cine* mode to collect the exit radiation and produce a sequence of images for each field. An in-house program was developed for calculating the location of the fiducials and their relative distance to the planned locations.
Results: Three case studies illustrate the utility of the technique. Patient A exhibited a systematic shift of 4 mm during one of the treatment beams. Patient B showed an inferior drift of the target of approximately 1 cm from the time of setup to the end of the fraction. Patient C had a poor setup on the first day of treatment that was quantified and accounted for on subsequent treatment days.
Conclusions: Target localization throughout each treatment beam can be quickly assessed with the presented technique. Treatment monitoring with an EPID in *cine* mode is shown to be a clinically feasible and useful tool.

SBRT, Respiratory motion, Organ motion, EPID.

INTRODUCTION

There is considerable interest in adopting stereotactic radiosurgical techniques for extracranial treatment sites, also known as stereotactic body radiotherapy (SBRT) (1–4). Studies have already demonstrated the benefit of hypofractionation for the treatment of liver metastases and primary and metastatic lung tumors using a body frame and compression plate (5, 6). However, hypofractionated treatment is predicated on a high accuracy and precision of tumor localization before *and during* each therapy session. It is assumed that the residual motion of the tumor during treatment will be the same as it was during simulation, not only in magnitude but also in direction. Although there are published studies that quantify the residual motion of liver tumors during simulation (7), we are not aware of any published data on intrafraction motion during SBRT treatment. To ensure that the tumor is within the treatment field *during* treatment, it (or an appropriate surrogate) must be imaged *during* treatment.

In this article a method is presented for monitoring liver tumors with implanted fiducials during SBRT using an electronic portal imaging device (EPID). Data from early patient studies demonstrate the utility and need for this type of imaging. Although several researchers have proposed tracking internal fiducial markers using kilovoltage (kV) X-rays within the treatment room (8–11), in-room kV sources are not yet standard equipment in most radiotherapy clinics. By contrast, many new brands of linear accelerator (LINAC) come equipped with an EPID and software to process, view, and catalogue the images. The source for EPID images is the LINAC's megavoltage (MV) beam—the same one that is used for treatment. The Varian EPID (Varian Medical Systems, Palo Alto, CA) has a *cine* mode, in which sequential images are acquired whether or not the beam is even on (images collected when the beam is gated off, for example, are blank). The user can accumulate serial images during treatment with minimal effort. The benefits of patient imaging during treatment with an EPID vs. a gantry- or room-mounted kV source include:

1. Dose. No additional imaging dose is given if the treatment beam is being used for imaging. (According to a study by Kilby and Savage [12], the increase in exit skin dose due

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to backscatter from the EPID is approximately 1% for a treatment beam of 6 MV, 10 × 10 field at 10 cm distance from the skin to the EPID.)
2. Perspective. The images are acquired in the beam's-eye-view. They show what is actually being irradiated. Although the view is two-dimensional, dosimetrically, the third dimension (depth) is not as important for X-ray irradiation. One would need a minimum of two fluoroscopic kV units, separated by roughly 30°–150°, to provide similar information (11).
3. Effort. No additional maintenance effort is needed or infrastructure required.
4. Cost. An EPID is a standard feature on most new LINACs.

Detriments include:

1. Image quality. The image quality of MV images is inherently worse than for kV in the systems under study. Complex image processing procedures are needed to overcome this deficiency.
2. Acquisition speed (latency). The current PortalVision/EPID system does not have sufficiently fast acquisition and processing for on-line, real-time evaluation. This is not an intrinsic problem and may be solved through software/hardware upgrades.
3. Image frequency. Our current frame rate in *cine* mode is approximately 0.6 images per second, compared with 30 images per second for commercial kV systems. Like acquisition speed, this may be improved with software/hardware upgrades.

Keall *et al.* (13) performed phantom tests with an EPID to assess the feasibility of tracking implanted fiducials in the presence of periodic motion. They found that the marker positions in a solid water phantom could be found automatically and proposed using this system for tumor tracking. As they point out, though, beam tracking with only an EPID is not practical owing to the possibility of obscuration of the seeds by the multileaf collimator leaves. With the technique presented in this article, it will also be possible to determine whether beam tracking is even needed in the case of SBRT. Ford *et al.* (14) developed a method for determining residual organ motion during gating by manually triggering the EPID during treatment and finding the location of the diaphragm in each image. However, the diaphragm may not always be a viable surrogate (especially for small SBRT fields and non-coplanar beams), and the relationship between diaphragm position and tumor position has not been established.

The feasibility of the method presented in this article was first tested by Berbeco *et al.* (15) for a gated liver treatment. A similar idea was proposed, contemporaneously, by Baier and Meyer (16). In the work of Berbeco *et al.*, gold seeds were implanted on the periphery of the tumor, and data were taken using a method similar to the one described below. The results showed that the residual motion of the tumor, within the externally defined gating window, was within the planned limits. In addition, this study demonstrated the utility of the EPID verification method for ensuring a safe treatment. This becomes increasingly important as fractionation and safety margins are decreased and dose increased, as in the case of SBRT.

In the present study we have extended the *cine* EPID method to continuous (non-gated) SBRT. In the SBRT treatments we present, the field sizes are smaller, fractional dose greater, and number of treatment days significantly reduced compared with the gating scenario previously studied. In addition, treatment/imaging is done through an immobilization device, and non-coplanar beams are introduced.

METHODS AND MATERIALS

Cine *EPID acquisitions during treatment*

Three patients were treated in the radiation oncology clinic of the Dana-Farber/Brigham and Women's Cancer Center under a phase I institutional review board–approved SBRT protocol for limited hepatic metastases from solid tumors. All 3 patients, during this first phase, were treated in 3 fractions of 1000 cGy each, separated by approximately 48 h. Before treatment planning, multiple (three or more) gold fiducial markers are implanted on the periphery of the tumor. The relationship between the marker locations and the tumor is determined in the computed tomography simulation session. For this session, patients are fit with a body frame and abdominal compression plate (Elekta Instruments, Stockholm, Sweden) (Fig. 1). However, even with the compression plate in place, there will still be some residual motion of the tumor. The extent of tumor residual motion is evaluated fluoroscopically with a Varian Ximatron simulator (Varian Medical Systems). The observed residual motion is included in the treatment margins for the radiotherapy treatment plan. A three-dimensional conformal treatment plan, based on a conventional (not four-dimensional) positron emission tomography/computed tomography scan, is created with multiple fields, some of them non-coplanar. Digitally reconstructed radiographs (DRRs) are produced for anterior–posterior (AP) and lateral (LAT) setup fields, as well as for each of the treatment fields. The seed contours are included in all of the DRRs.

At the time of treatment, the patient is placed in the body frame and compression plate and positioned on the treatment couch using the in-room lasers. Orthogonal portal images are used to ensure that the target—defined by the implanted fiducial markers—is in the reference position. A Varian 6ex with an AS500 EPID and PortalVision software for image review (Varian Medical Systems) was

Fig. 1. The body frame and compression plate used for immobilization of the patient and suppression of the internal motion.