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Physics Contribution

Active Breathing Control in Combination With Ultrasound Imaging: A Feasibility Study of Image Guidance in Stereotactic Body Radiation Therapy of Liver Lesions

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Summary

For image guidance, 3-dimensional ultrasound imaging in the stereotactic body radiation therapy of liver lesions is feasible. The use of surrogates in the close vicinity of lesions may be needed. The accuracy of 3-dimensional ultrasound image guidance is improved by using active breathing control; in free breathing the accuracy is 4 mm, and when it is combined with active breathing control the accuracy is 2 mm.

Purpose: Accurate tumor positioning in stereotactic body radiation therapy (SBRT) of liver lesions is often hampered by motion and setup errors. We combined 3-dimensional ultrasound imaging (3DUS) and active breathing control (ABC) as an image guidance tool.

Methods and Materials: We tested 3DUS image guidance in the SBRT treatment of liver lesions for 11 patients with 88 treatment fractions. In 5 patients, 3DUS imaging was combined with ABC. The uncertainties of US scanning and US image segmentation in liver lesions were determined with and without ABC.

Results: In free breathing, the intraobserver variations were 1.4 mm in left-right (L-R), 1.6 mm in superior-inferior (S-I), and 1.3 mm anterior-posterior (A-P). and the interobserver variations were 1.6 mm (L-R), 2.8 mm (S-I), and 1.2 mm (A-P). The combined uncertainty of US scanning and matching (inter- and intraobserver) was 4 mm (1 SD). The combined uncertainty when ABC was used reduced by 1.7 mm in the S-I direction. For the L-R and A-P directions, no significant difference was observed.

Conclusion: 3DUS imaging for IGRT of liver lesions is feasible, although using anatomic surrogates in the close vicinity of the lesion may be needed. ABC-based breath-hold in midventilation during 3DUS imaging can reduce the uncertainty of US-based 3D table shift correction. © 2013 Elsevier Inc.

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Introduction

Stereotactic body radiation therapy (SBRT) of liver lesions requires tight margins for safe treatment with high radiation doses while limiting the normal liver dose. Accurate daily localization of the treatment target is highly important. Organ motion and patient setup are potential error sources. Currently, image guided radiation therapy (IGRT) is mostly based on x-ray imaging (eg, electronic portal imaging [EPI] and cone beam [CB] computed tomography [CT]). For liver lesions, however, these techniques provide inadequate imaging contrast. EPI images of bony anatomy cannot deal with the liver motion related to breathing and stomach and bowel filling. Case et al (1) assessed the interfraction and intrafraction variability of the liver position, treated with kV CBCT-guided SBRT. They demonstrated that interfractional liver position relative to the vertebral bodies is a source of geometric uncertainty. To alleviate the poor x-ray imaging contrast in soft tissue, fiducial markers have been proposed as a surrogate. Marker-guided setup accuracy decreases with increasing distance between the fiducial markers and the tumor (2). Furthermore, implanting fiducial markers is invasive and can result in tumor spread, liver inflammation, and embolization (3). Although kV CBCT may allow visualization of liver boundaries, the lesion or nearby blood vessels are not clearly visible. Furthermore, CBCT image quality is limited because of breathing artifacts leading to motion aliasing. The time to acquire a CBCT image makes breathing control problematic. The recently reported respiratory correlated CBCT (4D-CBCT) (1, 4) may solve the motion-related artifacts but will not solve the poor soft-tissue contrast.

A clear need is identified for an alternative imaging technique to guide radiation therapy. A reduction of geometric uncertainties may lead to reduced normal tissue irradiation, safer dose escalation, and improved local control for patients with hepatic malignancies. Ultrasound (US) imaging may offer a solution. In radiation therapy this is a fairly new technique, although it has been used extensively for many years as 2-dimensional (2D) US imaging in diagnostic radiology because of the high soft tissue contrast of US imaging. The feasibility of US imaging was demonstrated (5) for liver guidance, using the BAT device (Nomos, Cranberry Township, PA). This allows for superposition of anatomic contours derived from treatment planning CT onto real-time US images, for liver image guidance. The use of 2 different image modalities in an intermodality system, however, introduces additional uncertainty.

We investigated the use of an intramodality 3-dimensional (3D) US system as a novel IGRT application in liver treatment. The intramodality approach entails comparing US images acquired in the treatment room with a reference US image acquired at the time of CT simulation. The goal is to establish the accuracy of 3DUS imaging with and without active breathing control (ABC) for IGRT of liver lesions.

Methods and Materials

Eleven patients (Table 1) were included in this study (1 patient was not included in the study because of bad sonographic visibility). All patients gave written informed consent before entering this study, which was approved by the internal review board.

3DUS system

The Clarity intramodality US imaging system (Elekta, Stockholm, Sweden) was used for this study in a total of 88 treatment fractions. The system comprises 2 interlinked US stations, based in the CT room (US-Sim) and in the treatment room (US-Guide). Each US station is equipped with a 2DUS probe (3.3 MHz) designed for abdominal scanning and a ceiling-mounted infrared stereovision camera. Four reflective markers are attached to the probe and are tracked in real time by the infrared camera to determine the position and orientation of each ultrasound frame. The 2DUS frames are then reconstructed in space to form a 3DUS voxel dataset. These 3DUS images are calibrated to the room coordinate system of the corresponding CT and treatment room to allow a direct comparison of the reference 3DUS images at simulation with those acquired in the treatment room (referred to as image segmentation). From this, the difference in daily position of the lesion is derived, resulting in an absolute shift to reposition the patient for treatment.

Our first experiences in liver scanning demonstrated that, with the current transabdominal probe design, it is difficult to maintain a direct line of visibility between the reflective markers and the optical tracking system during scanning. This is due to the position of the markers on the probe, the wide range of angles of the probe during scanning, and the range of positions of the probe on the skin under various orientations. To obtain optimal scanning and probe tracking conditions for IGRT in liver lesions, we redesigned, in collaboration with the manufacturer, the reflective marker array fitted onto the curved abdominal probe (Fig. 1a). To ensure the accuracy of the prototype probe in relation to the room coordinates, a daily calibration check was performed before each treatment session. The uncertainty for each US station was within 1 mm, resulting in a combined uncertainty of 2 mm for the whole quality assurance procedure.

ABC system

For breathing control we used the Spiro SDX system (DynR, France), designed for radiation therapy. The system relies on maintaining a certain breath-hold (BH) volume to fix the position of the lesion absolutely in space. The spirometer is connected to the patient by use of a mouthpiece with a nose clip to prevent nasal air leakage (Fig. 1b). The spirometry sensor measures the patient's breath flow (L/sec). A predefined BH level can be set, and video goggles guide the patients to this predefined level. We used 50% of the tidal volume for BH (midventilation, 50% expiration), referring to the breathing phase used for treatment planning (50% expiration based on respiratory-correlated CT imaging [RCCT]).

We verified that both spirometers used (in CT and treatment rooms) did not deviate by more than 0.01 L from a precisely known volume of 3 L, well within the manufacturer's specified 2% uncertainty.

US procedure

We combined ABC with breathing feedback to the patient, in combination with 3DUS imaging. Before the first session, the patient was trained to become comfortable with the spirometer and video goggles and to determine the individual tidal volume