MRI method developments for stand-alone MRI and CT fiducial-based registration

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Introduction: Implanted fiducial point-based co-registration of magnetic resonance (MR) images to radiotherapy planning computed tomography (CT) images achieves the necessary registration accuracy to improve target delineation, reduce treatment volumes, and further limit radiation dose to organs-at-risk. Standard T2-weighted fast-spin-echo images enable delineation of the prostate boundary, but do not amplify locations of implanted gold fiducial markers (FM). A second technique (i.e. gradient-echo imaging) may then be required to demarcate FM locations confidently, which prolongs scan times and sensitizes the registration process to motion (1). This research investigates potential stand-alone MRI techniques for FM-based registration at 1.5 Tesla. Specifically, steady-state-free precession (ssfp) and T2-prepared spiral imaging (T2prep) present with T2 or T2-like contrast and focal dipolar field amplification, because of the ssfp frequency response and the off-resonance blur function of spiral k-space sampling (Fig. 1) (2,3).

Methods: Fifteen patients with low and intermediate risk localized prostate cancer underwent MR imaging prior to radiotherapy planning but following ultrasound-guided insertion of three gold FM (0.8mm diameter, 3.0mm long cylinders) into apical, mid, and base prostate locations. MRI acquisition was performed on a 1.5-Tesla GE Signa with patients in supine position using the 4-coil torso array for signal reception. For 15 patients, confidently-detected seeds in standard T2-weighted images, termed 3mm-FSE, (TE/TR = 106/4000ms, 0.78x0.78x3mm voxels) were counted retrospectively by 3 reviewers (prostate radiation oncologist, fellow, radiation therapist). For 5 patients, additional 'registration' images were acquired using clinical optimizations, specifically (a) 2mm-FSE (TE/TR = 48/6000ms , 0.78x0.78x2mm voxels), (b) 3d-ssfp (TE/TE = 1.6/5.7, 0.78x1.04x2mm voxels); and (c) T2prep (TE/TR = 50/4400ms, 1.1x1.1x3mm voxels). The image sets were judged for FM visibility and ease of delineating the prostate boundary by 4 reviewers (2 prostate radiation oncologists and 2 clinical fellowship trainees), based on a set of 5 questions, namely: (1) how many FM can be confidently detected; (2) how clear is the edge of the prostate boundary; (3) how clear is the prostate apex; (4) how clear is the prostate base; and (5) rank the methods for ease of delineation (1-best; 4-worst). Questions 2 through 4 were answered based on a 5-point scale, as follows: (1) no better than CT; (2) difficult; (3) mediocre; (4) good; and (5) excellent. Scores for questions 2 through 5 were summated across all reviewers, so that scores of 60% and 80% of maximum values were deemed mediocre or good overall. All image reviews were performed on a Pinnacle workstation (Phillips Medical Systems), with concurrent CT and MR image visualization approximately registered using a mutual information algorithm.

Results: In the 15-patient cohort, the untrained fellow, trained clinician, and experienced radiation therapist detected 53%, 77%, and 91% of FM (24 of 45, 33 of 45, 41 of 45). FM implanted in the base seemed to be more challenging to detect, presumed to be due to greater motion at the base through the course of the acquisition. This result validates the overall inadequacy of the standard diagnostic methods for MR–to-CT FM-based registration in planning radiotherapy. In the 5-patient review, the 3mm-FSE, 2mm-FSE, 3d-ssfp, and spiral methods detected 51%, 72%, 98% and 100% of FM. Based on summated scoring, 3mm-FSE was best for contouring of the edge (83%, compared to 68-72% for other methods), apex (77%, compared to 73% for T2prep, 68% for 2mm-FSE, and 60% for ssfp), and base (80% of possible points, compared to 73% for 2mm-FSE, 65% for T2prep, and 53% for ssfp). 3mm-FSE was deemed best overall for prostate boundary delineation, followed by 2mm-FSE, T2prep, and ssfp. Trained reviewers preferred the FSE approaches for delineation of prostate targets, while the untrained fellow expressed a greater preference for ssfp and T2prep, though only the latter two approaches consistently demarcated all FM. Specific reviewer comments included reduced vessel/prostate contrast at the rectal/prostatic angle for T2prep acquisitions, reduced relative capacity of ssfp to delineate the apex and base, and a good ability of all approaches to demarcate the lateral boundaries.

Summary and Conclusions: Given the small volume of current FM and underlying prostate motion, consistent FM conspicuity is not achievable using standard diagnostic imaging methods at 1.5 Tesla, even when the slice thickness is reduced to 2mm. Ssfp and T2-prepared spiral imaging provide adequate contrast for contouring with consistent FM visibility in acquisitions, which progresses the design of stand-alone radiotherapy planning pulse sequences at 1.5 Tesla. This analysis may guide the development of a training platform for prostate radiotherapy planning for both fellows and therapists.

References: (1) Parker et al. *Radiotherapy and Oncology*, 2003; (2) Foltz et al. *Magn Reson Med*, 2003; 3) Kerkhof et al. *Phys Med Biol*, 2008.

Figure (A) Amplification of a gold FM embedded in agarose gel using (left) FSE and (right) T2-prep acquisitions at equivalent resolution to clinical methods; (B) Representative (i) 3mm-FSE, (ii) 2mm-FSE; (iii) ssfp, and (iv) T2prep images at middle levels of the prostate. A FM is clearly visible as a focal hypointensity in 2mm-FSE, ssfp, and T2prep images, but poorly defined in the 3mm-FSE acquisition.