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Reduction of MRI signal distortion from titanium intracavitary brachytherapy applicator by optimizing pulse sequence parameters

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ABSTRACT

PURPOSE: To demonstrate that optimized pulse sequence parameters for a T2-weighted (T2w) fast spin echo acquisition reduced artifacts from a titanium brachytherapy applicator compared to conventional sequence parameters.

METHODS AND MATERIALS: Following Institutional Review Board approval and informed consent, seven patients were successfully imaged with both standard sagittal T2w fast spin echo parameters (voxel size of $0.98 \times 0.78 \times 4.0$ mm^3; readout bandwidth of 200 Hz/px; repetition time of 2800 ms; echo time of 91 ms; echo train length of 15; 36 slices; and imaging time of 3:16 min) and an additional optimized T2w sequence (voxel size of $0.98 \times 0.98 \times 4.0$ mm^3; readout bandwidth of 500 Hz/px; repetition time of 3610 ms; echo time of 91 ms; echo train length of 25; 18−36 slices; and imaging time of 1:15−2:30 min), which had demonstrated artifact reduction in prior phantom work. Visualized intracavitary tandem was hand-segmented by two of the authors. Three body imaging radiologists assessed image quality and intraobserver agreement scores were analyzed.

RESULTS: The average segmented volume of the intracavitary applicator significantly ($p < 0.05$) decreased with the experimental pulse sequence parameters as compared to the standard pulse sequence. Comparison of experimental and standard T2w sequence qualitative scores for each reviewer showed no significant differences between the two techniques.

CONCLUSIONS: This study demonstrated that pulse sequence parameter optimization can significantly reduce distortion artifact from titanium applicators while maintaining image quality and reasonable imaging times.

Keywords: MRI; Cervical cancer; Brachytherapy; Distortions; Artifacts

Introduction

The use of MRI to plan brachytherapy (BT) treatment for cervical cancer has shown superior contrast for defining the tumor and clinical target volume and decreased dose to normal tissues relative to CT-based plans (1, 2). In addition, the use of magnetic resonance (MR)-based BT planning is increasing, (3) given the availability of MR conditional (4, 5) applicators. However, applicators made from nonferrous metals cause geometric distortion or imaging artifacts, reducing the utility of MRI for dosimetry (6, 7). An ideal BT-planning MR sequence identifies the placement of the applicator in relation to the lesion; assesses disease treatment response (8), as serial examinations are common given fractionated dosing (9); and optimizes lesion conspicuity and soft tissue contrast-to-noise ratio while minimizing artifacts and imaging time.

In general, objects that cause distortions in MR images have significantly different magnetic susceptibilities than the surrounding tissue, which results in varying magnetic fields around these objects (10), giving rise to imaging artifacts. Increasing readout bandwidth and spatial resolution mitigates the distance at which the susceptibility difference will affect the surrounding tissue. This is a well-established method of reducing artifact and is well reported in the musculoskeletal imaging literature (11), given the frequent need to image prostheses. Unfortunately, these sequence

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parameter changes reduce signal-to-noise ratio (SNR) and increase imaging time, necessitating a compromise to minimize acquisition time.

Prior work by Haack *et al.* and Kim *et al.* (6, 7) examining titanium applicators in both phantoms and patients focused mainly on quantifying the amount of geometric distortion for a particular imaging sequence protocol and did not specifically compare different parameter sets within a particular sequence class (i.e., fast spin echo (FSE), gradient echo, etc.). A prior phantom study by our group (12) specifically looked at the effects of spatial resolution and readout bandwidth on tip location and size in two-dimensional (2D) T2-weighted (T2w) FSE sequences, which are predominantly used to contour lesions in MR-guided cervical BT. One T2w sequence parameter set, which increased readout bandwidth while also slightly decreasing spatial resolution, reduced tip artifact as compared to a standard T2w parameter set and did not increase imaging time while only moderately decreasing SNR. Imaging time is an important factor to consider as T2w sequences are typically acquired in three separate image orientations and additional time increases the probability of gross patient motion as well as increasing patient discomfort. The purpose of this study was to demonstrate that this optimized T2w MR sequence reduces artifact caused by a BT applicator compared to a standard T2w sequence while also preserving image quality.

Methods

Patient enrollment and procedure

Following Institutional Review Board approval, nine patients scheduled for MRI-based high-dose-rate (HDR) BT were prospectively recruited and informed consent was obtained for all subjects. These patients originally presented with locally advanced cervical cancer and had already received external beam radiation therapy, 45−50.4 Gy, plus concurrent cisplatin (13−16). The patients underwent placement of the tandem and ovoid applicator (Fletcher-Suit-Delclos-style applicator with flexible geometry, AL13030001; Varian Medical Systems, Palo Alto, CA) by the radiation oncologist and gynecologic oncologist in the operating room under general anesthesia. After placement and recovery, patients were imaged with MRI. The MR images were interpreted by a diagnostic radiologist and used for treatment planning by the radiation oncologist and medical physicist. Patients received two fractions of HDR BT treatment in one implant on subsequent days with a single night in the hospital between fractions. Patients then returned 1−2 weeks later for repeat applicator placement, MRI, and two additional fractions of BT.

MRI technique

The MRI protocol for planning at our institution consists of sagittal, coronal, and axial T2w FSE acquisitions covering the cervix, uterus, and applicator plus an axial T1w FSE sequence of the pelvis in concordance with The Groupe Européen de Curiethérapie, European Society for Radiotherapy & Oncology recommendations (17−19). To this protocol, we added an experimental sagittal T2w FSE acquisition with increased readout bandwidth. Each patient was imaged on a 1.5T MRI system (Magnetom Aera, Siemens Healthcare, Germany) with the tandem and ovoid applicator in place. Standard sagittal T2w FSE parameters at our institution were a voxel size of $0.98 \times 0.78 \times 4.0$ mm^3; readout bandwidth of 200 Hz/px; repetition time (TR) of 2800 ms; echo time of 91 ms; echo train length of 15; 36 slices; and imaging time of 3:16 min. Seven patients were imaged with an additional experimental T2w sequence with a voxel size of $0.98 \times 0.98 \times 4$ mm^3; readout bandwidth of 500 Hz/px; TR of 3610 ms; echo time of 91 ms; echo train length of 25; 18−36 slices; and imaging time of 1:15−2:30 min. Slice coverage was reduced in the experimental protocol in most patients to only cover the area proximal to the tandem to keep additional imaging time to a minimum. Inadvertently, two additional patients were imaged with a different set of experimental parameters and were thus excluded from analysis.

Measurements

To assess perceived applicator size, the intracavitary portion of the applicator was manually segmented on both standard and experimental T2w sequences by two reviewers (SS and TS) using viewing and segmentation software (Velocity AI 3.2; Varian Medical Systems, Palo Alto, CA). To ensure consistency between reviewers, only the top 5 cm of the intracavitary applicator was segmented. This corresponded to an actual applicator volume of 0.476 cm^3.

While making volumetric measurements, we noted that differentiating fluid within the endometrial cavity from applicator bright signal artifact was often difficult, as both can appear bright on T2w images. (Note that the off-resonance from a metal object will cause both high- and low-signal artifacts.) In response to this, two sets of measurements were made. The first set, "high−low," included the high signal around the low signal void of the applicator, with exclusion of regions which were thought to represent only fluid. The second set, "low," measured the low signal void region, which was thought to represent only the core of the applicator. See Fig. 1 (b) and (d) for an example of segmentations.

Measurements were made based upon window-level settings for each image series determined by consensus of both reviewers in an individual session 5−7 days before any measurements were performed in an effort to decrease recall bias. Volumetric measurements were drawn independently by each reviewer during two separate sessions. The "standard" image series and "experimental" image series were measured at least 5 days apart to limit bias in measurements as visual differences between the experimental and standard images were agreed by both reviewers to be obvious.