Imaging Protocol Optimization for MR-only HDR Brachytherapy Treatment Planning

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2026 JULY 19–22 VANCOUVER, BC
JOINT AAPM | COMP MEETING

ABSTRACT

Purpose: To optimize a simulation imaging protocol for MR-only treatment planning (MRTP) of high-dose rate (HDR) brachytherapy (BT) in patients diagnosed with prostate cancer.

Methods: Under IRB waiver, MRI sequences were added to the treatment simulation protocol for 3 patients undergoing HDR BT to optimize contrast between patient anatomy and interstitial needles containing Orion fiducial markers (C4 Imaging). Imaging was performed on a 1.5T Siemens Sola scanner. An iterative optimization process was performed on several axial 3D MRI sequences (T2 SPACE, CISS, and TRUFI) by maximizing spatial resolution, minimizing artifacts, and maintaining an SNR of at least 25. Optimized MR sequence parameters are listed in Table 1, including FOV, matrix, voxel size, TR/TE, averages, acceleration, and scan time. Contrast-to-noise ratio, CNR = $|S_1 - S_2| / \sigma_0$, was measured for each sequence using mean signal in the needle (S_1), mean signal in the surrounding tissue (S_2), and standard deviation of the noise (σ_0).

Results: Figures 1 & 2 display axial images of each 3D sequence and sagittal MPRs of the TRUFI sequence for each patient, used to visualize the end of the needle tip. The T2-weighted SPACE sequence demonstrates negative contrast in the needle with respect to the surrounding tissue, while the T2/T1-weighted CISS and TRUFI sequences show positive contrast of the needle due to their balanced, steady state acquisitions. Figure 3 shows the average CNR of each sequence, with error bars denoting standard deviation; SPACE yielded the lowest CNR, while TRUFI yielded the highest.

Conclusion: This work demonstrated the optimization of a simulation imaging protocol for MR-only treatment planning of HDR brachytherapy in patients with prostate cancer. A T2/T1-weighted 3D TRUFI sequence outperformed a SPACE and CISS sequence when measuring the contrast of the needle to the surrounding tissue, thus offering better visualization of the needle trajectory and tip.

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INTRODUCTION

MR-only treatment planning (MRTP) for HDR brachytherapy has been explored as a means to eliminate the need for CT from hybrid CT/MR-based workflows[1].

Recently, **MR-visible line markers** have shown added value in MR-only workflows, improving catheter reconstruction from MR images in the setting of interstitial gynecological HDR brachytherapy[2].

However, **sequence improvements** can be made to MR acquisitions to further enhance the contrast of these MR-visible markers in HDR needles.

This work seeks to **optimize a simulation imaging protocol** for MRTP of HDR brachytherapy in patients with prostate cancer.

METHODS

Under an IRB waiver, MRI sequences were added to the treatment simulation protocol for **3 patients undergoing HDR brachytherapy**.

Imaging was performed on a **1.5T Siemens Sola scanner** dedicated to MR simulation in the Radiation Oncology department.

Contrast between patient anatomy and interstitial needles containing **Orion fiducial markers** (C4 Imaging, Bellaire, TX) was optimized.

An iterative process was performed by maximizing spatial resolution, minimizing artifacts, and maintaining an SNR of at least 25 on **several fluid-sensitive 3D MRI sequences**:

- **AX T2 SPACE** (Sampling Perfection with Application optimized Contrasts using different flip angle Evolution)
- **AX T2/T1 CISS** (Constructive Interference in Steady State)
- **AX T2/T1 TRUFI** (True Fast Imaging with Steady-State Free Precession)

Unlike the T2-weighted SPACE sequence, the CISS and TRUFI sequences demonstrate **mixed T2/T1 contrast** characteristic of steady state MR acquisitions.

Contrast-to-noise ratio, CNR = $|S_1 - S_2| / \sigma_0$, was measured for each sequence using mean signal in the needle (S_1), mean signal in the surrounding tissue (S_2), and standard deviation of the noise (σ_0).

Optimized MR sequence parameters are listed in Table 1, including FOV, matrix, voxel size, TR/TE, averages (NSA), acceleration, and scan time.

Sequence	FOV (mm)	Matrix	Voxel Size (mm^3)	TR/TE (ms)	NSA	Acceleration	Scan Time (m:ss)
SPACE	256 x 256	256 x 256	1 x 1 x 1	1200/119	2	CS 10.5	4:54
CISS	150 x 150	256 x 192	0.6 x 0.8 x 1	6.1/3.1	1	-	5:45
TRUFI	150 x 150	256 x 256	0.6 x 0.6 x 1	6.7/3.3	1	GRAPPA 2	5:04

Table 1. Imaging Simulation Protocol Parameters for MR-only Treatment Planning in HDR Brachytherapy

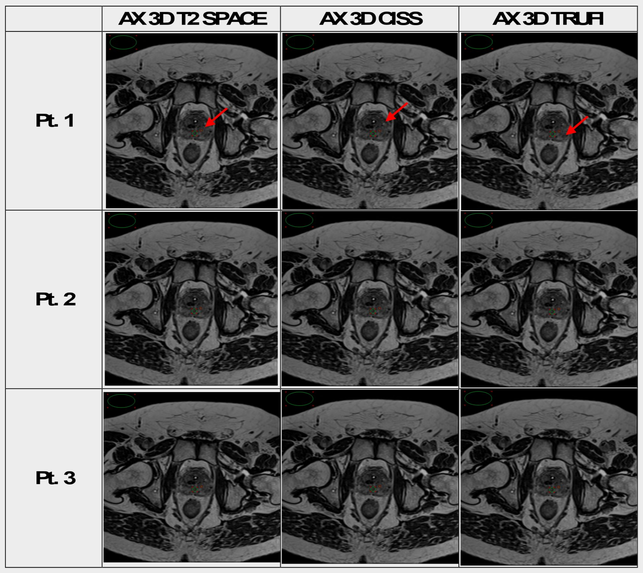

Figure 1. MR images of each axial 3D sequence. Green ROIs for Pt. 1 demonstrate location of signal measured in needle (red arrow) and surrounding tissue; noise measured in ROI outside patient on SPACE and in another slice on CISS and TRUFI due to small FOV.

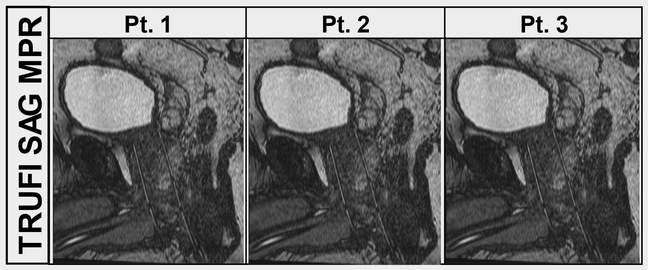

Figure 2. Sagittal MPRs of the TRUFI sequence for each patient.

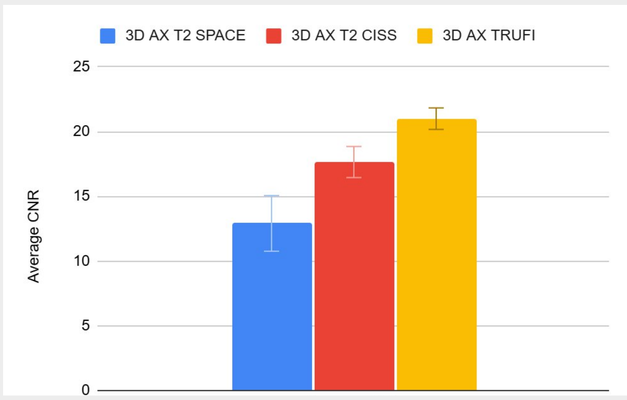

Figure 3. Average contrast-to-noise ratio (CNR) of each sequence, with error bars denoting standard deviation.
SPACE: 12.91 ± 2.15; CISS: 17.65 ± 1.20; TRUFI: 21.00 ± 0.83.

RESULTS

Figure 1 displays axial images of each sequence for all 3 patients, with red arrows showing location of marker-enhanced needles.

Figure 2 displays sagittal multi-planar reconstructions (MPRs) of the TRUFI sequence for each patient, used to visualize the end of the needle tip.

T2-weighted SPACE sequence demonstrates **negative contrast** in the needle with respect to the surrounding tissue

T2/T1-weighted CISS and TRUFI sequences show **positive contrast** of the needle due to their steady-state acquisitions.

Figure 3 shows the average CNR of each sequence, with error bars denoting standard deviation; SPACE yielded the lowest CNR, while TRUFI yielded the highest.

CONCLUSION

This work demonstrated the **optimization of a simulation imaging protocol for MR-only treatment planning** of HDR brachytherapy in patients with prostate cancer using MR-visible needle markers.

A **T2/T1-weighted 3D TRUFI sequence outperformed SPACE and CISS** sequences when measuring the contrast of the needle to the surrounding tissue, thus offering better visualization of the needle trajectory and tip.

IMPACT

MR-only treatment planning of HDR brachytherapy will require **accurate placement of the needles** in the treatment model.

This is **challenging with 3D T2 SPACE** sequences with negative needle contrast.

This work **optimizes the contrast and image quality for a T2/T1-weighted 3D TRUFI sequence** with positive needle contrast.

REFERENCES

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