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Evaluation of T2-weighted MRI Pulse Sequence for Visualization and Sparing of Urethra with MR-guided Radiation Therapy (MRgRT) on-board MRI

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INTRODUCTION

Stereotactic body radiation therapy (SBRT) for prostate cancer has become prevalent due to its comparative effectiveness, shorter treatment times and patient acceptance. However, higher dose results in higher rates of acute and late gastrointestinal (GI) and genitourinary (GU) toxicities. GU toxicities can arise due to any complications along the GU tract[1]. Urethra sparing through delineation of the prostatic urethra is a challenging, yet nontrivial way to decrease urethral toxicity.

In conventional CT-based radiation therapy, some centers choose to roughly contour the prostatic urethra based on prior knowledge and or using a Foley catheter. However, these methods are inconsistent and unreliable. MRI can be registered to improve urethra delineation, however, the associated MR to CT registration error can be around 2 mm^2. Alternatively, MR-guided based radiation therapy (MRgRT), avoids cross-modality registration planning errors. Furthermore, MRgRT can minimize GI and GU toxicity through tighter planning target volumes margins and daily plan adaptation/re-optimization[3].

PURPOSE

In this study, we sought to optimize 2 urethral T2-weighted MRI sequences with a 0.35T MRgRT system for visualization and delineation of the prostatic urethra. We compare MRgRT workflow with the optimized urethral sequence to CT-based workflows.

METHOD

- 7 prostate cancer patients
  - Imaging
    1. Planning CT
    2. 1.5T Diagnostic T2-weighted MR
    3. 0.35T MRgRT 3D TrueFISP
    4. **0.35T MRgRT urethral 3D HASTE**
    5. **0.35T MRgRT urethral 3D TSE**

Table 1: Optimized urethral sequence parameters

Parameter		
Sequence	3D HASTE	3D TSE
Relaxation time	1800 ms	2000 ms
Echo time	246 ms	250 ms
Flip angle	180°	180°
Bandwidth	196 Hz/Px	351 Hz/Px
Resolution	1.5 x 1.5 x 1.5 mm^3	1.5 x 1.5 x 1.5 mm^3
Number of averages	6	4
Acquisition duration	8:06 minutes	7:14 minutes

- Treatment planning/urethra contouring workflows
  1. Method 1: CT-based with CT only
  2. Method 2: CT-based with CT and registered diagnostic MR
  3. Method 3: MRgRT-based with optimized urethral sequence

- Evaluation metrics
  - Qualitative
    - For each workflow, a radiation oncologist scored urethra visibility on a 4-point scale

Table 2: Urethra visibility score

Score	Meaning
1	No conspicuity
2	Some conspicuity; urethra can be identified, but not very clear
3	Good conspicuity; urethra can be identified clearly based on MRI only
4	Excellent conspicuity

  - Quantitative
    - Using MRgRT workflow as baseline, all images were registered, and prostatic urethra contours were evaluated relative to 3D HASTE using:
      - Hausdorff distance (HD)
      - Mean-distance-to-agreement (MDA)
      - DICE coefficient

RESULTS

Table 3: Patient urethra visibility scores

Patient	1. CT	2. CT + Registered diagnostic T2w MRI	3. 3D HASTE	3. 3D TSE
1	1	2	3	3
2	1	3	3	2
3	1	3	3	2
4	2	1	3	3
5	2	2	3	3
6	2	2	3	2
7	1	2	3	2

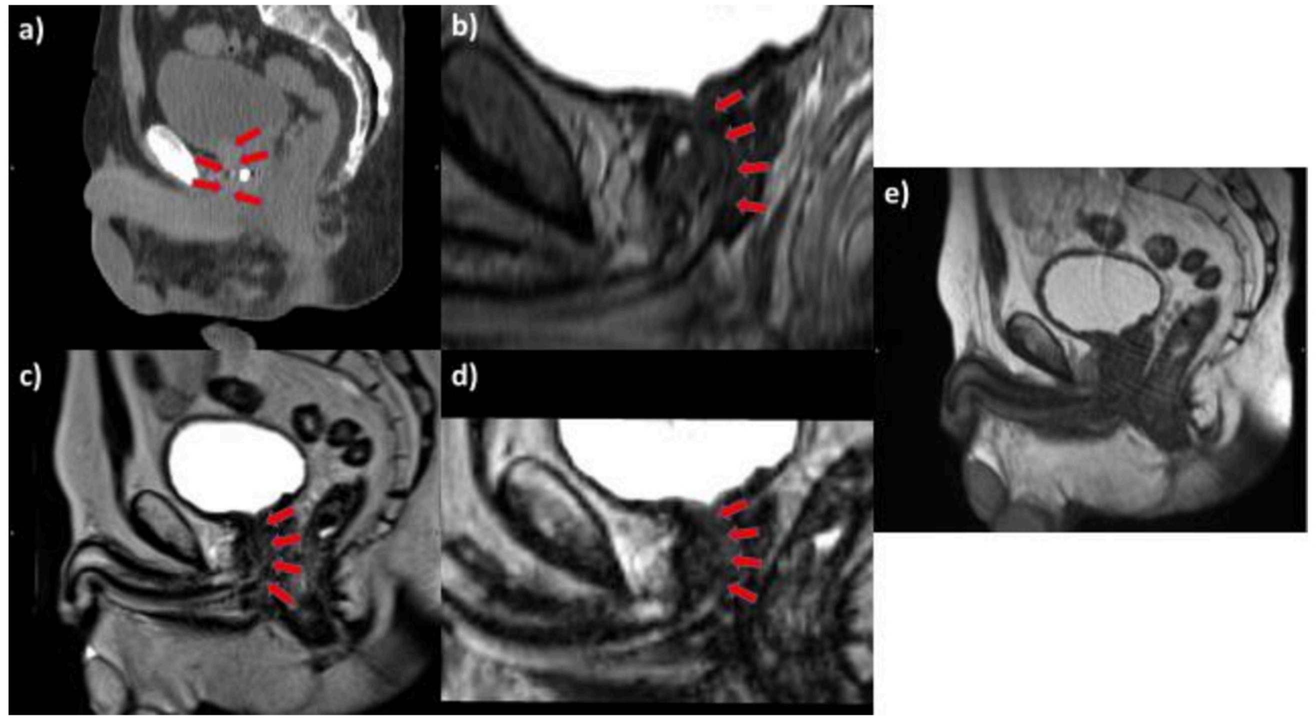

Figure 1: Patient 7's a) CT, b) diagnostic MR, c) 3D HASTE, d) 3D TSE, e) 3D TrueFISP

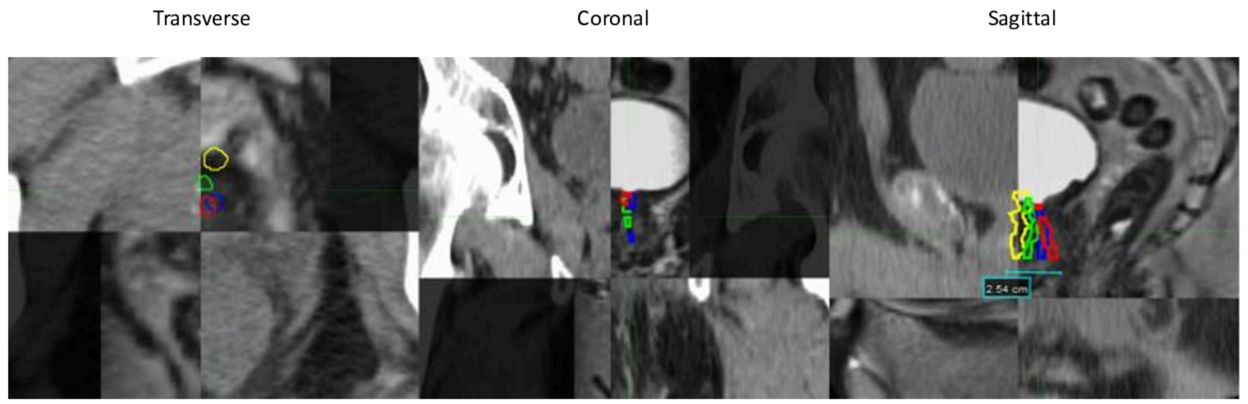

Figure 2: Patient 7's urethra contours from CT only (yellow), CT + diagnostic MR (green), 3D HASTE (red), 3D TSE (blue) planning

Table 4: Patient's mean and standard deviation Hausdorff distance (HD), mean-distance-to-agreement (MDA), and DICE coefficient

Method 1: CT	HD (mm)	MDA (mm)	DICE
Mean	14.68	5.30	0.12
Standard Deviation	3.20	2.11	0.11
Method 2: CT + diagnostic MRI			
Mean	11.47	3.98	0.15
Standard Deviation	4.15	1.99	0.18
Method 3: 3D TSE			
Mean	6.64	1.47	0.45
Standard Deviation	2.01	0.59	0.15

Overall, MRI provides urethral contrast, whereas CT does not. 3D HASTE consistently performed best for urethra visibility. From Figure 1, compared to 3D TSE, HASTE had higher SNR, resulting in a less grainy prostate and easier urethra visualization. Quantitatively, from Table 4, the CT and MR based workflows showed significant prostatic urethra localization disagreement. High urethra contouring accuracy and precision is critical for urethra sparing and radiation therapy efficacy as significant treatment errors could occur if cold dose regions are not positioned correctly. MRgRT workflow avoids additional cross-modality registration and can minimize organ contouring uncertainty.

CONCLUSIONS

Two 0.35T MRgRT pulse sequences were proposed for urethra visualization and prostatic urethra contouring. 3D VR HASTE provided high contrast and spatial resolution for prostatic urethra delineation. MRgRT workflow avoids cross-modality registration errors and allows for accurate urethra delineation and effective urethra sparing during both initial MRgRT treatment planning and on-line adaptive radiation therapy.

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