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Single-Fraction Stereotactic MR-Guided Adaptive Radiotherapy: Evaluation of Plan Efficiency and Quality

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SUMMARIZED ABSTRACT

Purpose: This work evaluates single-fraction MR guided adaptive radiotherapy (SMART-1fx) plan quality relative to RTOG-0813 standards.

Methods: A retrospective analysis was performed on patients treated with SMART-1fx between 2020-2025. Step-and-shoot IMRT was delivered on a 0.35 T MR-Linac. Efficient beams/segments were prioritized. Online adaptation was performed when necessary to meet OAR constraints. Plan quality was compared to RTOG-0813 no / minor / major deviation thresholds for PITV, D2cm, and R50%.

Results: 87 plans were evaluated. Lesions were in the lung (n=27, 30-34 Gy), liver (n=29, 30-40 Gy), pancreas (n=12, 20-30 Gy), adrenal gland (n=9, 25-34 Gy), abdominal/pelvic lymph nodes (n=8, 25-30 Gy), celiac plexus (n=1, 25 Gy), and kidney (n=1, 26 Gy). Median total in-room time was 66 minutes. ART was used in 45% of cases and median PTV was 16.9 cc (3.7-273.5 cc). Average PITV, D2cm, and R50% were 1.10+/-0.17, 53%+/-7%, and 5.70+/-2.32, respectively. For RTOG-0813 thresholds, two plan quality metrics (PITV, D2cm) for most plans showed no (75%, 68%) or minor (25%, 30%) deviations. In general, R50% performed poorly with 20%/41%/39% of plans having no/minor/major deviations, respectively. Lung plans had larger mean R50% of 7.24+/-1.31, with 81% of plans classified as major deviation.

Conclusion: To our knowledge, this is the largest evaluation of single-fraction stereotactic MR-guided treatment plans. Favorable plan quality metrics were reported, and efficient treatment delivery times were achieved using modulation reduction techniques.

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INTRODUCTION

Single-fraction stereotactic radiotherapy is a common approach for treatment of intracranial lesions, but less widespread for other anatomic sites due to proximity of dose-limiting organs-at-risk. However, single-fraction SBRT offers benefits of convenience, cost-efficiency, improved coordination with systemic therapy, and potentially stronger radiobiological and immune effects relative to multi-fraction SBRT.

Technical limitations of conventional linear accelerators, like poor CBCT soft-tissue contrast and lack of real-time imaging or adapting capabilities, increase concerns of geometric misses. Real-time magnetic resonance (MR) image guidance and online adaptive radiotherapy (oART) enable a safe approach to such single-fraction treatments. Previously, the SMART ONE trial (NCT04939246) [1] demonstrated safe, feasible, and effective delivery of single-fraction stereotactic MR-guided adaptive radiotherapy (SMART-1fx) with 96.2% 1-year local control and no late G3+ toxicities.

In this work, single-fraction SMART plan quality in an expanded cohort is reported in comparison to standards set forth by RTOG-0813.[2]

METHODS AND MATERIALS

We retrospectively reviewed patients treated at our institution during 2020-2025 with SMART-1fx on a 0.35 Tesla MR-Linac with standardized methods:

Simulation
- MR-only (abdomen) or MR+CT (pelvis/thorax)
- Maskless immobilization with one, both, or neither arms overhead depending on site

Treatment Planning
- Step-and-shoot IMRT technique
- Limits enforced on plan modulation (beams /MLC segments) to reduce overall treatment time

Treatment Delivery
- Continuous, real-time MR during treatment
- Gated breath-hold delivery for mobile targets
- Supplemental oxygen when tolerated
- Abdominal compression belt when necessary
- Online adaptation performed when indicated

Plan Quality Metrics
- PTV coverage = V100% / PTV volume
- PTV D95%, D90%
- PITV = Rx isodose volume / PTV volume
- D2cm = max dose 2 cm from PTV / Rx dose
- R50% = 50% isodose volume / PTV volume

PITV, D2cm, and R50% were compared to RTOG-0813 thresholds of no, minor, and major deviation based on PTV size in cubic centimeters (cc).

Magnetic field (Bo) impact in low density medium by Lorentz Force was additionally investigated for lung plans with a single re-optimization at Bo=0 T.

RESULTS

87 SMART-1fx plans were identified with prescription doses of 20-40 Gy (60-120 Gy BED_{10}). 47% of patients were simulated with both arms down. Median PTV volume was 17 cc, ranging from 3-273 cc. **Table 1** lists median values of several treatment planning and delivery parameters sorted by anatomic site. Overall median total-in-room-time was 66 minutes with 78% of patients completing treatment in less than 90 minutes.

Median plan quality metrics are listed below. **Figures 1-2** showing variation in PITV and R50% values.
- PTV coverage: 93% ± 9%
- PTV D95% / D90%: 96% ± 12% / 101% ± 7%
- PITV: 1.10 ± 0.17 [75% no, 25% minor deviation]
- D2cm: 52% ± 7% [68% no, 30% minor deviation]
- R50%: 5.68 ± 2.29 [20% no, 41% minor deviation]

Lung plans demonstrated especially poor R50%:
- Lung: 7.24 ± 1.31 [81% major deviation]
- All other sites: 5.00 ± 2.35 [20% major deviation]

Re-optimizing lung plans with Bo=0T did not significantly (P=0.49) change R50% values.

Table 1. Treatment planning and delivery parameters for 87 single-fractions treatment plans across 7 anatomic sites.

Parameter (*Median Value)	Liver (n=29)	Lung (n=27)	Pancreas (n=12)	Adrenal (n=9)	Lymph Node (n=8)	Celiac Plexus (n=1)	Kidney (n=1)
Rx Dose [Gy]	30-40	30-34	20-30	25-34	25-30	25	26
# of beams/ segments*	15 / 25	15 / 30	19 / 40	17 / 25	18 / 32	21 / 39	16 / 24
Ungated delivery time* (min)	19.3	20.6	15.8	14.8	16.0	16.8	13.8
Total in room time* (min)	75	76	53	53	53	43	42
# Adapted	4 (14%)	3 (11%)	11 (92%)	7 (78%)	8 (100%)	0 (0%)	0 (0%)
% Using O2	90%	88%	75%	100%	88%	100%	100%

Figure 1. PITV relative to RTOG-0813 standards of major, minor and no deviation.

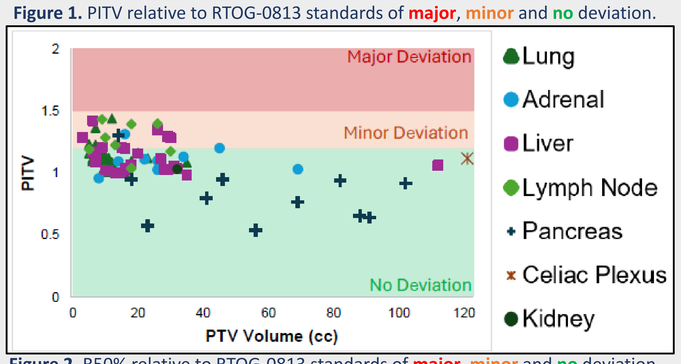
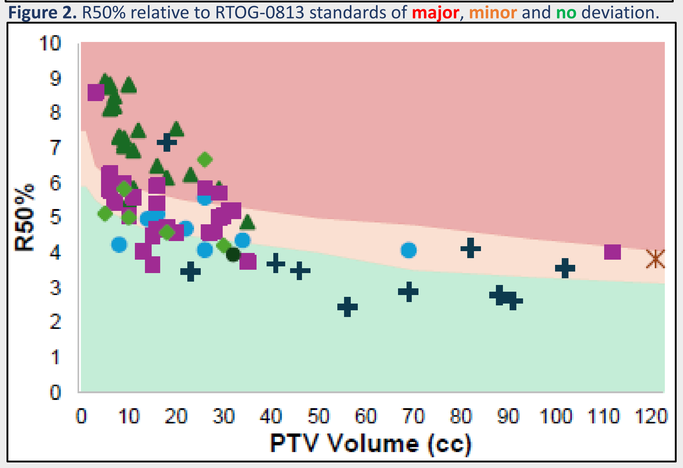


Figure 2. R50% relative to RTOG-0813 standards of major, minor and no deviation.



DISCUSSION

One of the largest challenges with extracranial single-fraction SBRT is achieving treatment times that patients can tolerate on the table. Most patients in this study completed treatment with 90 minutes. Reasonable treatment times were achieved through:
- Positioning the patient to increase time efficiency with target closer to MR and RT isocenter
- Limiting the number of beams and MLC segments allowed
- Performing online adaptation, when necessary, with parallel workflows for physician, physicist, and radiation therapist
- Providing supplemental oxygen to increase the patient's breath-hold duty cycle

Favorable plan quality metrics were reported, despite large targets near dose-limiting organs-at-risk. While most plans still had R50% without major deviation per RTOG-0813, it was the worst performing metric. Further investigation is needed to Evaluate whether R50% deviations were associated with adverse patient outcomes.

CONCLUSIONS

This is the largest evaluation of single-fraction stereotactic MR-guided adaptive radiotherapy treatment plans.

Favorable plan quality metrics were reported, particularly for PITV and D2cm, with most plans having no deviation per RTOG 0813. R50% values were poorer but could not be attributed to the electron return effect.

Single-fraction treatment delivery of 25-40 Gy was made feasible by standardized workflows and modulation reduction techniques.

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