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Commissioning and Initial Clinical Experience of Automated Breath-Hold Delivery on a 1.5 Tesla MR-linac

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IMPACT

Clinical Challenge:
- Compression belt is typically used to limit motion for abdominal SBRT on Unity MRL
- Leads to patient discomfort over long treatments
- Does not completely restrict motion and can deform organs into unfavorable geometry for treatment planning

Our Solution:
- Breath hold (BH) treatment limits target and OAR motion
- Smaller motion can enable tighter target margins and confidence for dose escalation
- We commissioned the CMM system for automated breath-hold treatment on the Unity
- One of the first sites worldwide to implement CMM BH for routine clinical use

Key Findings:
- Excellent agreement between static and BH delivery with gamma pass rates >98% at 3%/2mm
- Beam on/off latency and duty factors comparable to linac-based BH metrics reported in the literature
- Low Quality Factors (QF) were identified as the main treatment bottleneck and prevented beam-on even during acceptable breath-holds
- Understanding QF causes is critical for expanding clinical BH use

What We Report:
- Lessons learned and best practices for clinical implementation
- Practical guidance for improving treatment duty cycle
- Essential workflow details for sites adopting CMM BH gating

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INTRODUCTION

The breath-hold (BH) technique used in radiation treatment is an effective method to minimize respiratory motion and reduce intrafraction uncertainty of target position, which is especially important for high dose stereotactic body radiation therapy (SBRT) treatment. The Elekta Unity 1.5 T MR-linac offers real-time, high contrast MR imaging and superior target localization, especially for abdominal disease. The Comprehensive Motion Management (CMM) system released on the Elekta Unity enables automated beam hold, taking advantage of the continuous cine MRI visualization of the target, and can be used for motion management strategies including BH.
We report our clinical experience with MR-linac based BH treatment, including commissioning, clinical workflow, and treatment experience. Building upon previous work characterizing the accuracy of the CMM system, we focus specifically on the BH application, reporting on dose accuracy and latency. Our institution's clinical workflow for MRL BH treatment from simulation to treatment is outlined. Initial treatments focused on renal cell carcinoma targets as this site is significantly affected by respiratory motion and benefits from SBRT treatment.

	P1	P2	P3	P4
Dose/fx (Gy)	10	8	8	14
Avg MU / session	2172 ± 152	2670 ± 53	3374 ± 250	3612 ± 66
Avg session time (min)	34 ± 8	33 ± 7	31 ± 5	27 ± 3
Max session time (min)	46	42	39	31
Avg duty cycle	34% ± 9%	31% ± 6%	32% ± 4%	41% ± 4%
Min duty cycle	21%	24%	28%	37%
# fx using manual gating	1	3	0	0

Table 1: Treatment session duration and duty cycle information for each patient averaged across all delivered fractions.

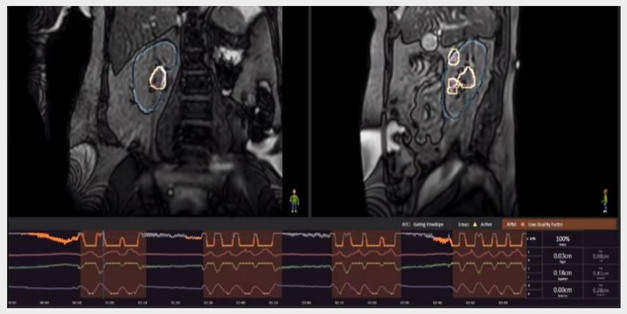

Figure 2: CMM screen during treatment. GTV is shown in a pink contour with a 3mm isotropic expansion representing the gating window. The kidney, contoured in blue, was used as the tracking structure. Orange shading indicates low quality factor.

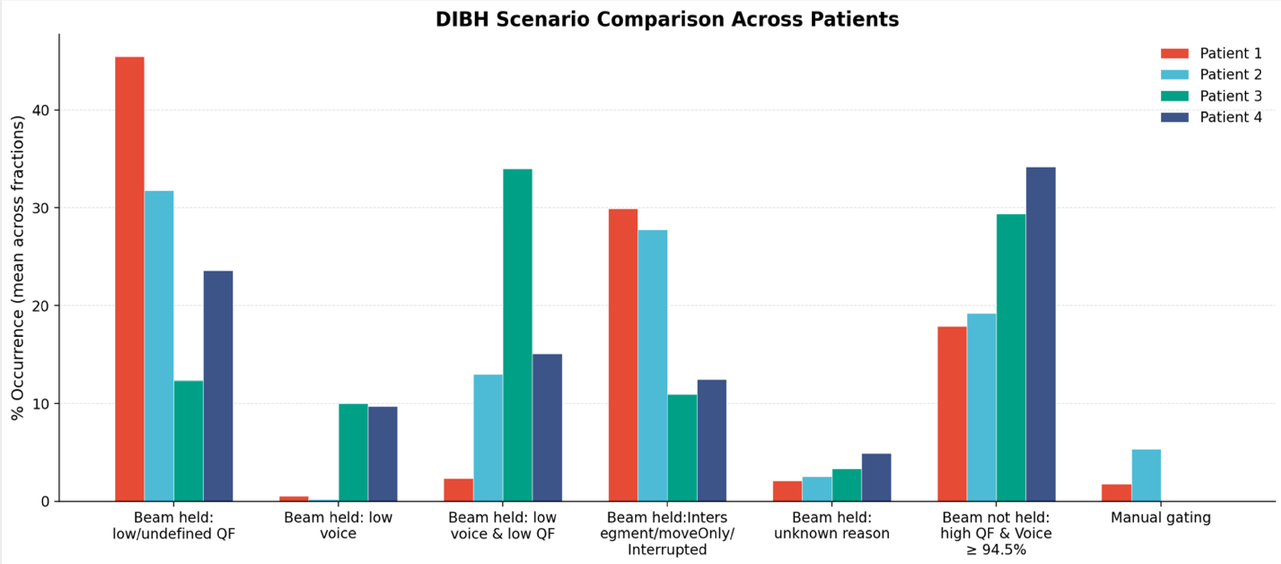

Figure 1: Bar graph depicting the beam status averaged across all sessions for each BH patient. The beam held status is divided into 4 different reasons why the beam was held, either intentionally or automatically, by the CMM algorithm: low Volume Overlap Coincidence (VOICE) of gating structure and gating window, low Quality Factor, intersegment motion/interruption, or unknown reason.

METHODS AND MATERIALS

Commissioning
- 2 clinical plans (central and lateral lesions) were delivered to film on a motion phantom with a 1-3cm range of motion in the superior-inferior direction, using the BH gated adaptive workflow with a 5mm gating envelope.
- Dosimetric evaluation of Gafchromic EBT-4 films irradiated during plan delivery was done via gamma analysis with 3%/2mm criteria.
- Gating latencies during beam-on and beam-off were measured.
- End-to-End (E2E) testing was performed to ensure dosimetric and localization accuracy met institutional standards.

Clinical Workflow
- 4 patients with adrenal targets were treated SBRT with BH on the Unity MRL Nov 2025-Mar 2026.
- Simulation involved MRI and CT scans with BH coaching and supplemental oxygen.
- MR sim sequences: 3D balanced fast field echo (bFFE) cines, T2-weighted, T1w Dixon.
- Consistency of BH was assessed by comparing kidney position between scans acquired at simulation and treatment.
- Planning involved drawing target contours on BH CT images using MR simulation sequences as reference.
- 9-15 field IMRT plans were designed to deliver the prescription dose in 3-5 fractions.
- Online plan adaptation involved pre-beam MRI acquisition, adaptive planning using ATS or ATP, and verification MRI to confirm patient position.
- During delivery, the CMM system provided real-time motion monitoring and beam gating.
- The Volume Overlap Coincidence (VOICE), indicating the percentage of target volume overlapping with the isotropic gating envelope, was set to 95% for beam gating.
- Patient coaching emphasized using repeated mid-inspiration breath-hold at a comfortable pace.
- During beam-on, patients were able to view an in-room video mirroring the CMM screen and visualize the MR cine with target and gating contours to assist with BH.
- Unity log file data was analyzed to determine duty cycle and algorithm factors affecting treatment.

RESULTS

Commissioning
Excellent agreement was found between static and BH gated deliveries, with gamma pass rates of >98.5% and average dose differences <1%. The E2E test passed institutional standards with a gamma pass rate of 98.9% and average dose difference of 0.7%. The measured beam-on latency was 2268 ± 341ms, which included the time when the lesion enters the gating window to beam on. The beam-off latency was 131 ±111ms.

Clinical Workflow
MR BH imaging at sim showed good agreement of kidney position between 3 consecutive BH scans with an average mean distance to agreement (MDA) of 1.39 ± 0.36mm and Dice coefficient of 0.88 ± 0.04, similar to the consistency seen in our standard-of-care CT BH sim images (MDA 1.14 ± 0.89mm, Dice 0.91 ± 0.07). In addition, BH kidney position in pre-beam MR scans at treatment were found to be reasonably reproducible, with mean MDA 2.02 ± 1.24mm, Dice 0.84 ± 0.11 across all fractions. The duty cycle for automatically gated fractions averaged 34.8 ± 7% with 29.9 ± 6 minute treatment times, consistent with 20-50% duty cycles reported for linac-based DIBH treatment. The algorithm detected low quality factors, related to image quality, resulting in beam hold for a significant portion of treatments. Manual gating was partially used in 4/18 fractions because of low QF. Using the kidney as the gating structure instead of GTV was found to improve QF.

CONCLUSIONS

We demonstrated successful commissioning and implementation of BH treatment for kidney tumors using the Elekta Unity CMM system and reported a comprehensive summary of our initial clinical experience as one of the first sites worldwide to adopt this technique. The duty cycle and latency were consistent with literature reports for linac-based DIBH treatment. The Unity CMM enabled accurate and clinically feasible BH treatment for SBRT of adrenal targets, though variability in BH and interruptions in beam delivery due to low quality factor suggest that improvements in treatment efficiency are possible. Practical recommendations to increase treatment efficiency include improved patient visual guidance, detailed patient coaching, and careful selection of tracking structures.

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