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National Center for
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عضو في مؤسسة حمد الطبية
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Real-Time Strategies

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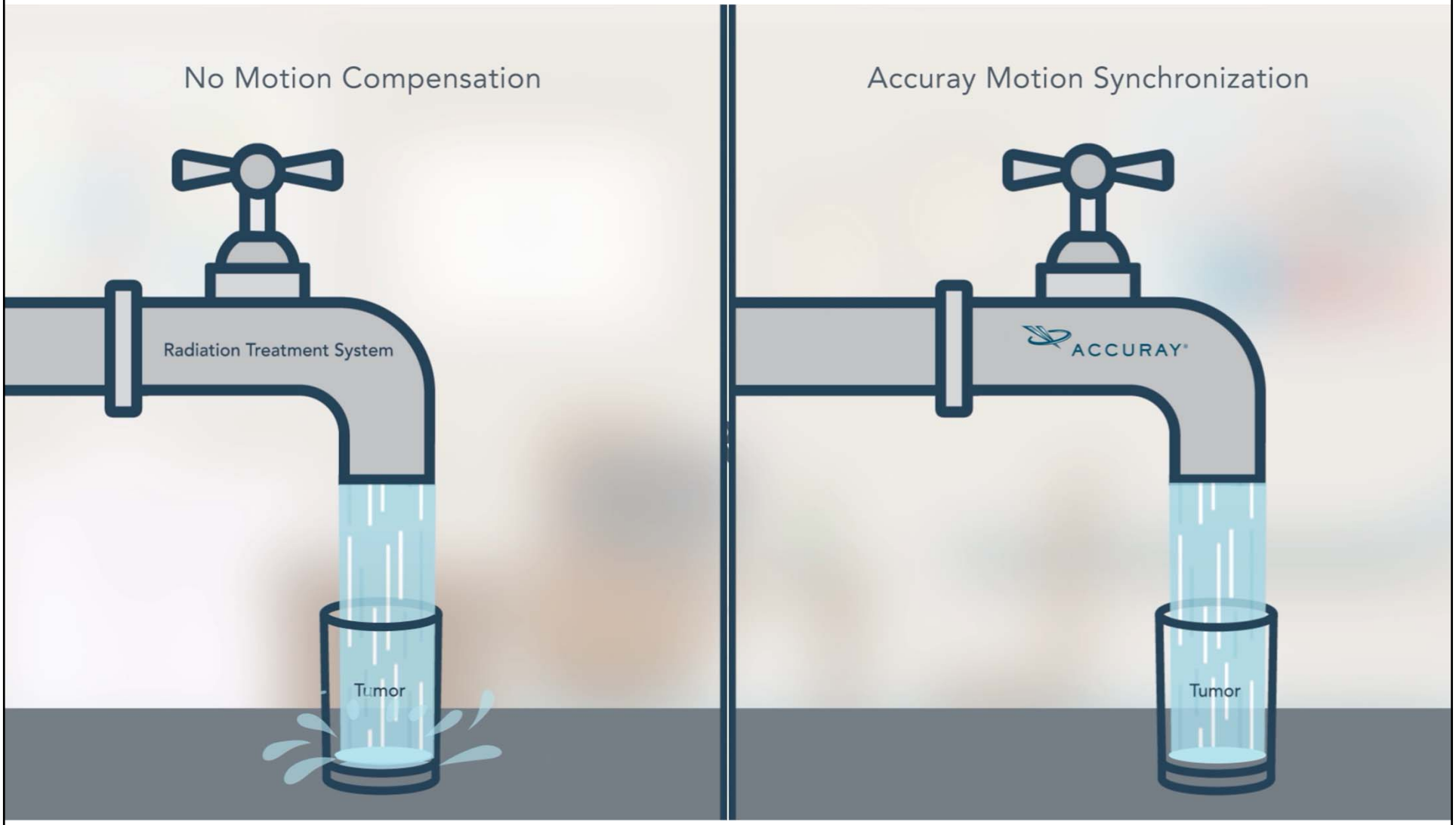
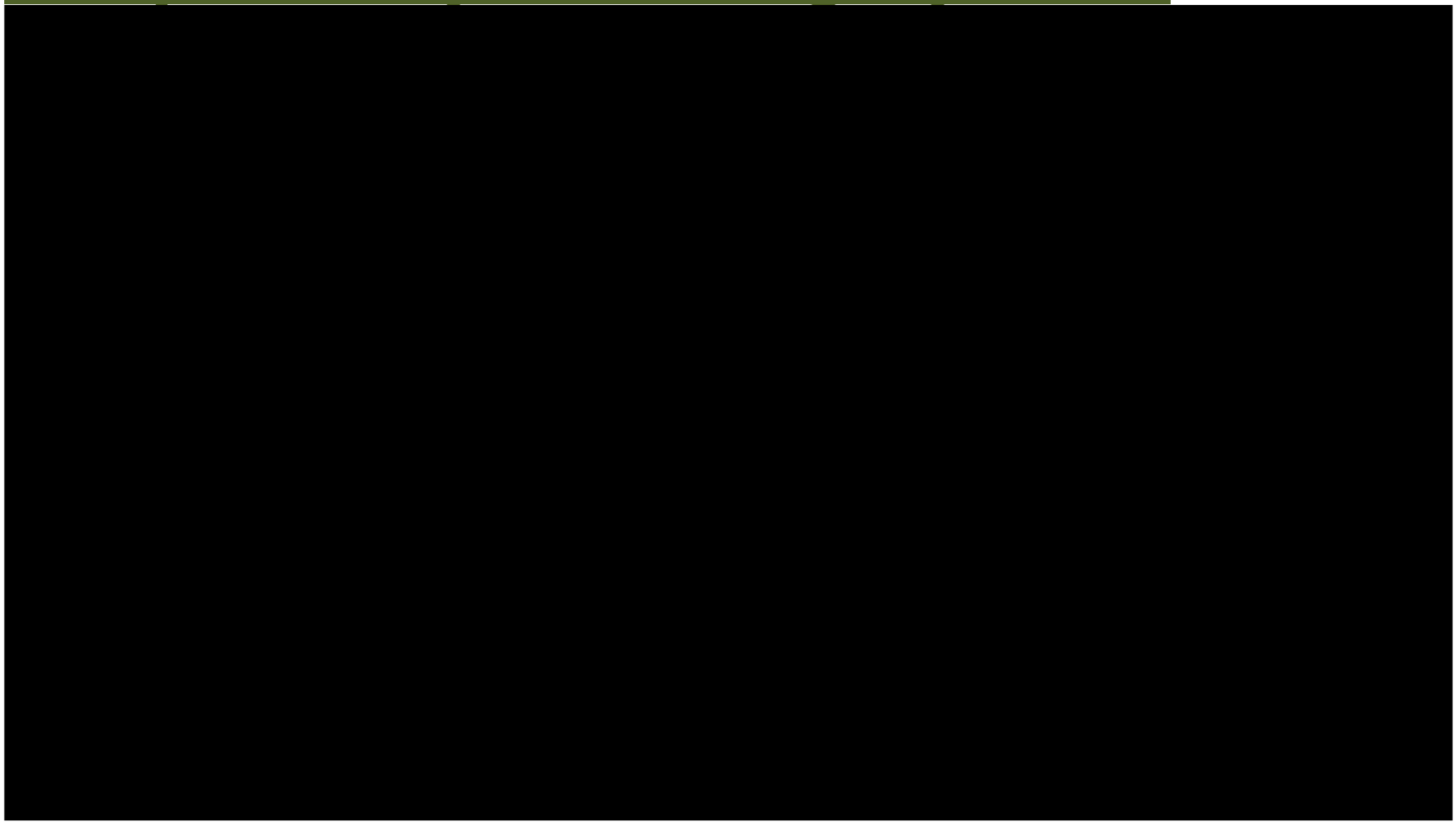
Objectives

- Motion tracking and other motion management strategies.
- CyberKnife® Realtime strategies – Synchrony Respiratory Tracking System
- The benefit of real-time strategy
- Evidence about the precision and accuracy of CyberKnife® Synchrony® and also clinical benefit.

Motion Management Strategies



CyberKnife® Synchrony® Respiratory Tracking System



- Benefits- Real Time Strategy
  - Delivered beams move in real-time with 3D target motion
  - Dose delivered continuously throughout the breathing cycle
  - Requires less PTV margin expansion
  - Minimized irradiation of healthy tissue or critical structures
  - Elimination of impractical and time-consuming gating and breath-holding techniques.
  - Direct tumor tracking allows for completely non-invasive, fiducial-free treatments with select patients

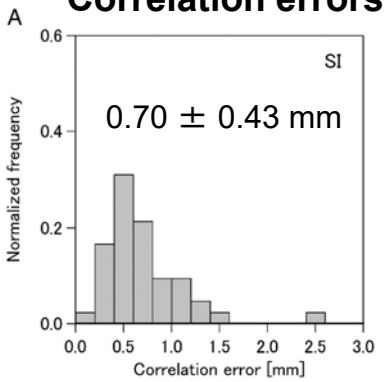
Evidence

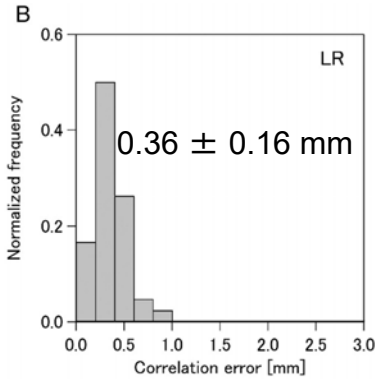
- Precision and accuracy of CyberKnife® Synchrony®.
- Clinical benefits of real time strategy

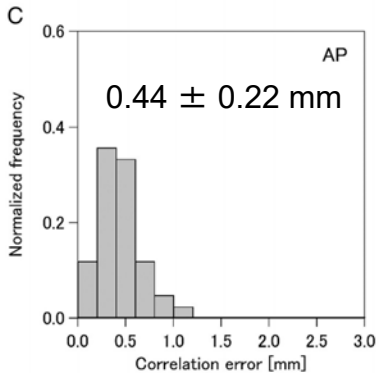
Clinical log data analysis for assessing the accuracy of the CyberKnife® fiducial-free lung tumor tracking system.

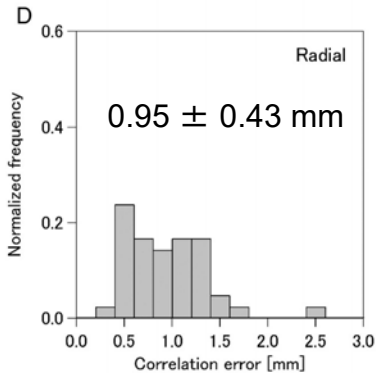
- 211 fractions in 42 patients with lung tumors.
- The mean correlation and prediction errors for each patient were calculated

Correlation errors

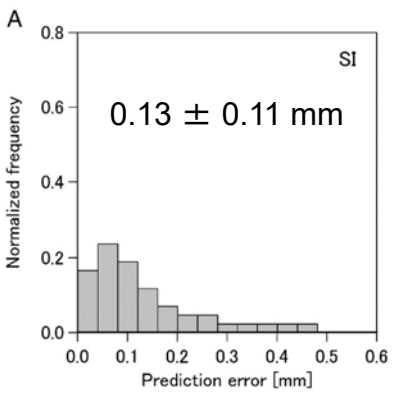


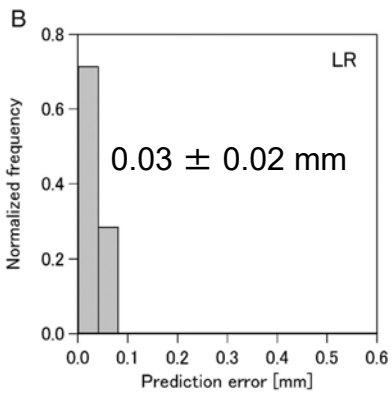


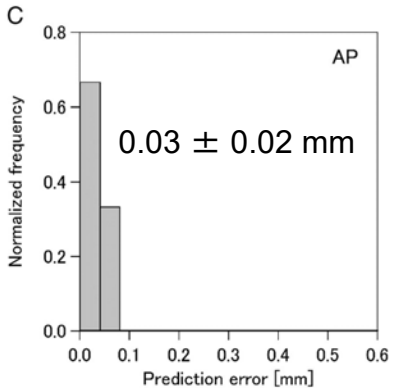


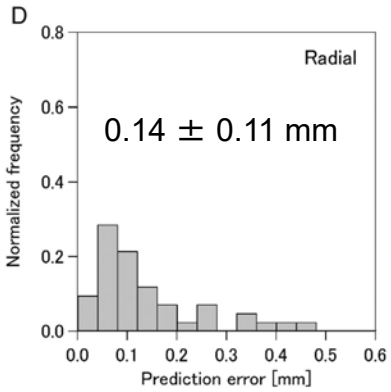


Prediction errors









Clinical log data analysis for assessing the accuracy of the CyberKnife fiducial-free lung tumor tracking system. Nakayama M, Nishimura H, Mayahara H, Nakamura M, Uehara K, Tsudou S, Harada A, Akasaka H, Sasaki R. Pract Radiat Oncol. 2018 Mar - Apr;8(2):e63-e70. doi: 10.1016/j.prro.2017.10.014. Epub 2017 Nov 4.
Division of Radiation Oncology, Kobe Minimally Invasive Cancer Center, Kobe, City, Hyogo, Japan.

4DCT prediction of inter- and intrafractional upper gastrointestinal tumor motion during fractionated stereotactic body radiation therapy.

14 patients – Fractionated SBRT – CyberKnife® with Synchrony®.

Fiducial motion was tracked for each phase of the respiratory cycle in Pre treatment 4D-CT scan

Real-time fiducial positions recorded during delivery - from the CyberKnife® planning system.

Displacements were compared between those predicted by 4D-CT and those recorded by Synchrony - LR, AP SI.

Four-dimensional computed tomography prediction of inter- and intrafractional upper gastrointestinal tumor motion during fractionated stereotactic body radiation therapy. Lischalk JW1, Kole TP2, Anjum HM2, Obayomi-Davies O2, Rashid A2, Unger K2. Pract Radiat Oncol. 2016 May-Jun;6(3):176-182. doi: 10.1016/j.prro.2015.10.006. Epub 2015 Oct 22.
Department of Radiation Medicine, Lombardi Comprehensive Cancer Center, Georgetown University Hospital, Washington, DC.

This study demonstrated significant inter- and intrafractional discrepancies, which could result in compromise of target coverage when planning with a single free-breathing 4D-CT.

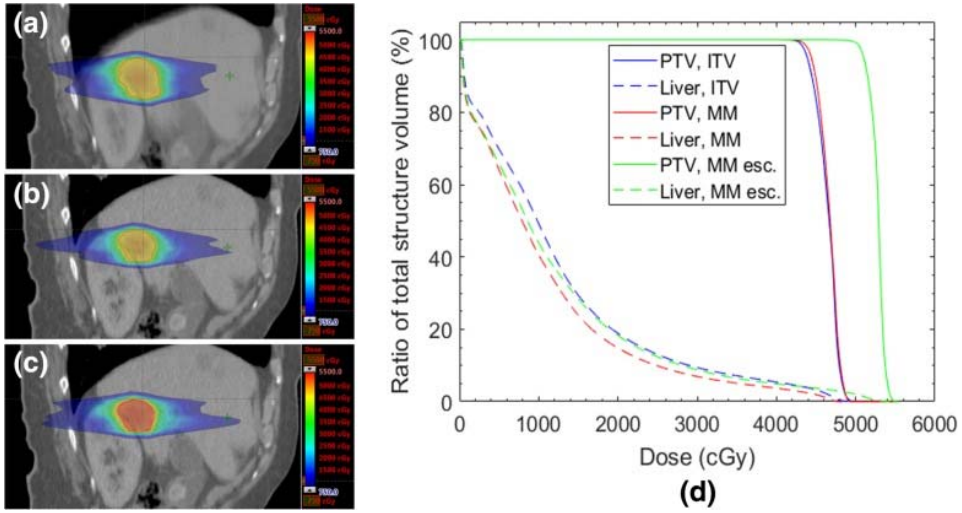
4D CT phase-averaged fiducial displacement (mm)	Superoinferior	Anteroposterior	Left-Right
Mean ± SD (range)	2.18 ± 2.14 (0.14-4.87)	1.20 ± 2.13 (0.14-3.34)	0.58 ± 1.82 (0.07-1.58)
Maximum ± SD (range)	3.86 ± 1.40 (0.26-7.37)	2.29 ± 1.02 (0.21-8.06)	1.45 ± 0.49 (0.11-6.79)

Fraction-averaged SBRT fiducial displacement (mm)	Superoinferior	Anteroposterior	Left-Right
Mean ± SD (range)	3.19 ± 2.21 (0.17-10.28)	1.27 ± 0.95 (0.08-3.64)	0.66 ± 0.51 (0.02-2.01)
Maximum ± SD (range)	10.73 ± 7.03 (0.91-31.60)	4.44 ± 3.33 (0.31-14.40)	2.67 ± 2.49 (0.15-10.23)

Four-dimensional computed tomography prediction of inter- and intrafractional upper gastrointestinal tumor motion during fractionated stereotactic body radiation therapy. Lischalk JW1, Kole TP2, Anjum HM2, Obayomi-Davies O2, Rashid A2, Unger K2. Pract Radiat Oncol. 2016 May-Jun;6(3):176-182. doi: 10.1016/j.prro.2015.10.006. Epub 2015 Oct 22.
Department of Radiation Medicine, Lombardi Comprehensive Cancer Center, Georgetown University Hospital, Washington, DC.

Clinical impact of removing respiratory motion during liver SABR

20 liver SABR patients
The treated PTV = ITV + 5mm margin. (ITV = GTV in all phases of 4DCT)
The intended prescription was 50Gy/5# (BED 100 Gy_{10}) [BED calculated with a/b ration=10]
Prescription was reduced by 2.5 Gy increments to meet liver dose constraints.
Motion eliminated plan PTV mm= GTV in the expiration phase + 5mm
All patients were re planned using the no-motion PTV (PTV motion managed)
Tumor dose was escalated to higher prescription levels without exceeding OAR constraints.



ITV – ITV-based, MM – motion managed,
MM esc – dose escalated motion management

(a)-the dose distribution - ITV method.
(b) -the re-plan using the motion managed PTV, same prescription level as in (a)
(c) the escalation of dose, from 42.5 Gy to 50 Gy whilst adhering to OAR dose tolerances.
(d) is a DVH demonstating PTV coverage (solid lines) for the three cases shown in (a) – (c), as well as liver dose (broken lines

M. Gargett C. et al Radiat Oncol. 2019; 14: 93. Published online 2019 Jun 3. doi: 10.1186/s13014-019-1300-6. Northern Sydney Cancer Centre, Australia

Correlation between PTV size and prescribed dose

- PTVs encompassing < 10% of the liver could receive the highest prescription
- 11/13 patients who was planned initially to a decreased prescription due to normal liver dose constraints, tumor dose escalation was possible using the nomotion PTV.

- Dose escalation in excess of BED 20 Gy_{10} increased the associated TCP by 5% or more.

Eliminating respiratory motion allowed dose escalation in the majority of patients studied and substantially increased TCP

M. Gargett C. et al Radiat Oncol. 2019; 14: 93. Published online 2019 Jun 3. doi: 10.1186/s13014-019-1300-6. Northern Sydney Cancer Centre, Australia

Normal Tissue Complication Probability Modeling of Pulmonary Toxicity After Stereotactic and Hypofractionated Radiation Therapy for Central Lung Tumors

Pooled analysis: central lung tumor treated using ≤12 fractions at 2 centers.

Airways were contoured on planning CT scans, Doses recalculated to an equivalent dose of 2 Gy per fraction with an α/β ratio of 3.

Grade ≥3 (≥G3) clinical pulmonary toxicity and Radiographic toxicity were evaluated

Clinical Grade >= 3 Toxicity- 24 patients (12%)

NTCP modeling showed a volume dependency for the development of both clinical and radiographic toxicity.

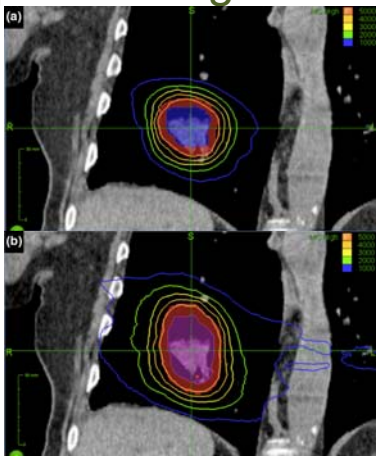
One of the predictor for ≥G3 toxicity- PTV overlapping the trachea or main stem bronchus.

Normal Tissue Complication Probability Modeling of Pulmonary Toxicity After Stereotactic and Hypofractionated Radiation Therapy for Central Lung Tumors. Tekatli H, Duijm M, Oomen-de Hoop E, Verbakel W, Schillemans W, Slotman BJ, Nuyttens JJ, Senan S. Int J Radiat Oncol Biol Phys. 2018 Mar 1;100(3):738-747. doi: 10.1016/j.ijrobp.2017.11.022. Epub 2017 Nov 21.

Influence of respiratory motion management technique on radiation pneumonitis risk with robotic SBRT

Examined the difference in radiation pneumonitis risk b/w RTT and ITV method using a normal tissue complication probability (NTCP) model.

20 lung SBRT treatment plans using RTT were replanned with the ITV method. Risk of symptomatic radiation pneumonitis was calculated for both plans using a previously derived NTCP model.



Planning and dosimetric characteristics of ITV and RTT plans.

	ITV		RTT		Pairwise difference (ITV – RTT)		
Target	Median	Range	Median	Range	Median	Range	P
PTV volume (mL)	60.0	21.3–160.6	33.1	6.6–88.2	17.1	3.5–72.4	<0.001
PTV/lung (%)	1.53	0.58–4.40	1.00	0.16–2.42	0.46	0.13–1.98	<0.001
PTV coverage (%)	95.5	95.0–97.0	95.6	95.0–96.7	0	−1.4 to 1.1	0.76
Rx IDL (%)	62.0	60.0–73.0	63.0	51.0–74.0	0.5	−13.0 to 10.0	0.92
Conformity index	1.08	1.01–1.19	1.10	0.98–1.36	−0.02	−0.32 to 0.10	0.19
Total MU	48,930	26,024–77,100	36,132	14,018–50,722	15,690	−8236 to 36,977	<0.001
Minutes per fraction	45.5	36–73	33	24–57	12.5	2–40	<0.001
Bilateral lung							
Mean (Gy)	8.20	3.84–18.7	5.49	1.72–11.95	1.95	0.22–7.37	<0.001
V2.5 Gy (%)	34.2	14.6–57.5	27.1	10.1–40.7	8.9	0.2–19.7	<0.001
V5 Gy (%)	22.7	8.3–41.5	18.3	5.5–32.9	3.4	−1.0 to 12.6	<0.001
V10 Gy (%)	13.6	5.3–29.0	11.0	3.5–21.3	2.0	−2.6 to 7.7	0.001
V13 Gy (%)	10.9	4.4–24.4	8.9	2.7–18.4	1.6	−2.6 to 6.3	0.004
V20 Gy (%)	7.7	3.3–16.1	6.2	1.7–13.0	1.0	−1.5 to 4.8	0.003
V30 Gy (%)	5.4	2.4–11.8	4.4	1.1–9.7	0.9	−1.0 to 3.4	0.002
V40 Gy (%)	4.2	1.9–9.5	3.4	0.8–7.8	0.8	−0.7 to 3.0	0.001
V50 Gy (%)	3.8	1.6–8.0	2.8	0.6–6.5	0.8	−0.6 to 2.6	0.001
NTCP (%)	8.9	3.5–41.1	5.1	2.1–17.2	1.9	0.4–25.5	<0.001

Median NTCP
5.1%-RT plans
8.9%-ITV plans

Gated VMAT vs. Tumor-Tracking CyberKnife® Radiotherapy as SBRT for Hepatocellular Carcinoma: A Dosimetric Comparison Study Focused on the Impact of Respiratory Motion Managements

29 HCC patients

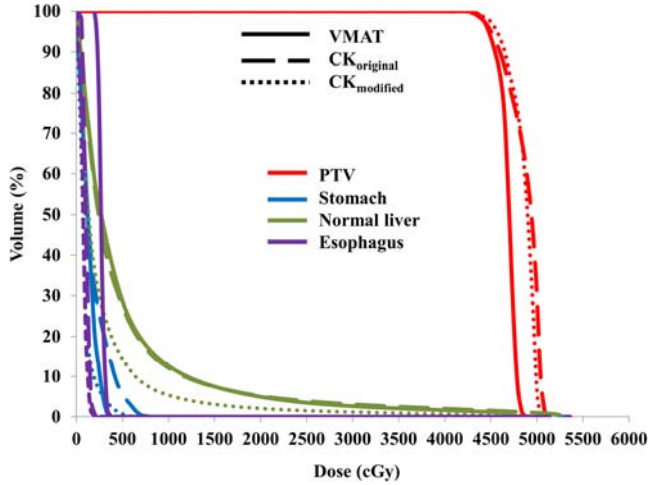
Previously treated with double-arc VMAT
ITV margin around the tumor - 30–70% of respiratory phases in 4DCT + 5-mm

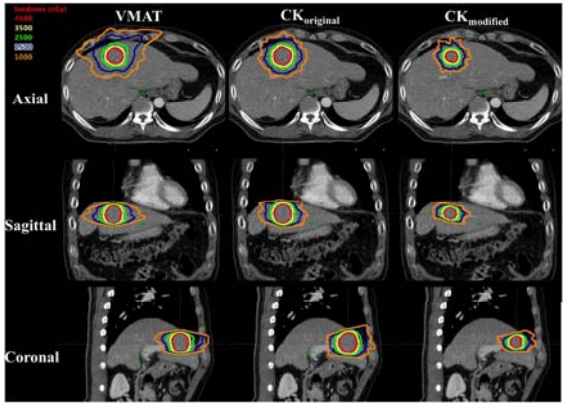
For each VMAT plan, two CyberKnife plans were generated.
- The original (CyberKnife original, ITV included),
- Modified PTVs (CyberKnife modified, ITV excluded).

Gated Volumetric-Modulated Arc Therapy vs. Tumor-Tracking CyberKnife Radiotherapy as Stereotactic Body Radiotherapy for Hepatocellular Carcinoma: A Dosimetric Comparison Study Focused on the Impact of Respiratory Motion Managements KyoungJun Yoon, Jungwon Kwak, Byungchul Cho,* Jin-hong Park, Sang Min Yoon, Sang-wook Lee, and Jong Hoon Kim. PLoS One. 2016; 11(11): e0166927. Published online 2016 Nov 22. doi: 10.1371/journal.pone.0166927
Yonsei University College of Medicine, REPUBLIC OF KOREA.

Mean CO, 93.0% in VMAT vs. 96.6% in CyberKnife® original and 96.9% in CyberKnife modified ($p < 0.001$).

The average volume of normal liver tissue receiving > 15 Gy was less in the CyberKnife modified plan, as compared to that in the VMAT and CyberKnife original plans





The tumor tracking capability of the CyberKnife® System can significantly decrease the volume of normal liver tissue receiving > 15 Gy, while maintaining high precision in target localization, conformity, tumor coverage, and dose sparing of the OAR.

Summary:

- There are different methods to manage the motion in the treatment of moving targets.
- Real time tumour tracking allows treatment of moving targets
  - without compromising the coverage
  - without inclusion of large amount of normal tissue.
- This allows escalation of the prescription dose and there by increase the TCP
- One of the parameter that predicts the treatment related toxicity
  - inclusion of large volume of normal structures in the treatment volume.
- Avoidance of large volume of normal tissue decreases the side effects of radiation.
- CyberKnife® System with synchrony tracking allows real time tumour tracking with sub millimeter accuracy and precision.

Thank you