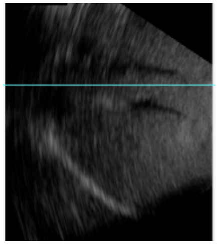
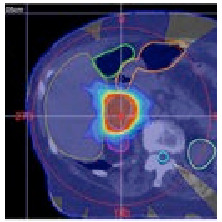
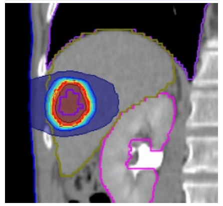
Optimales Motion-Management bei Tumoren des Oberbauchs

PD Dr. Judit Boda-Heggemann
Klinik für Strahlentherapie und Radioonkologie
Universitätsklinikum Mannheim

30.09.2022, Erlangen, Stereotaxie reimag^{in}ed

Target and OAR motion (abdomen)

1. breathing
2. organ filling/ peristaltic motion – deformation, non-linear dislocation

↓

- direct effect on PTV margins, dosimetry, coverage
- predictable/possible effect on toxicity and outcome (LC)

↓

Motion management strategies:

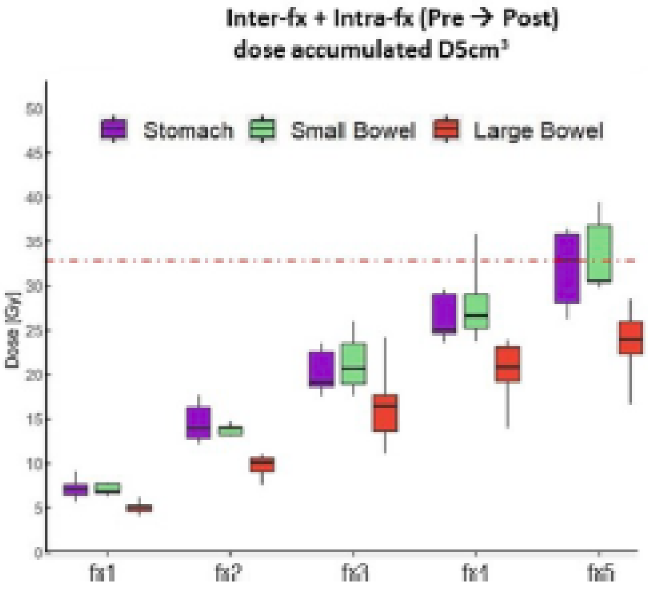
- Motion-estimation
- Motion-mitigation/compensation (ALARA for OAR, steep gradients)

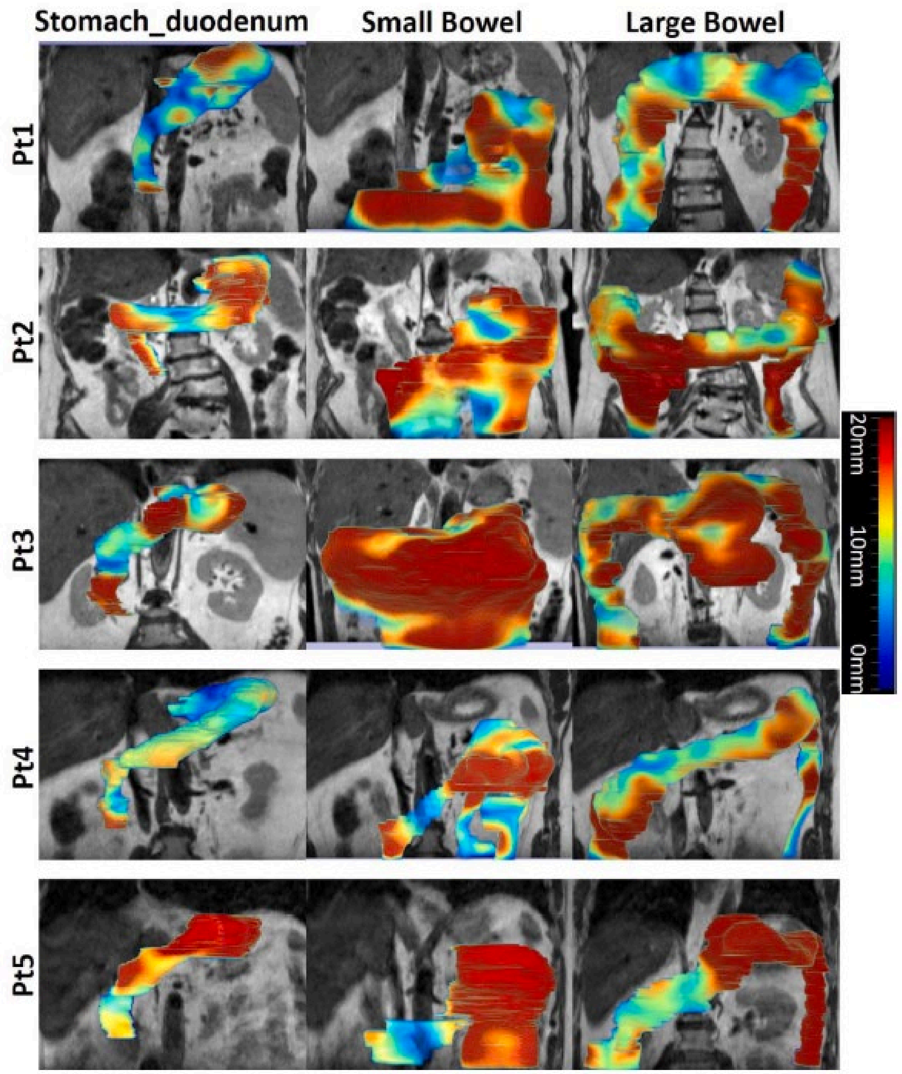
Motion assessment/ dosimetric consequences

Inter- and intrafraction motion assessment and accumulated dose quantification of upper gastrointestinal organs during magnetic resonance-guided ablative radiation therapy of pancreas patients

Sadegh Alam [a], Harini Veeraraghavan [a], Kathryn Tringale [b], Emmanuel Amoateng [b], Ergys Subashi [a], Abraham J. Wu [b], Christopher H. Crane [b], Neelam Tyagi [a,*]

Physics and Imaging in Radiation Oncology 21 (2022) 54–61



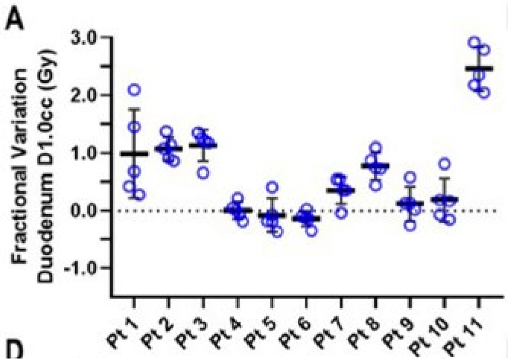


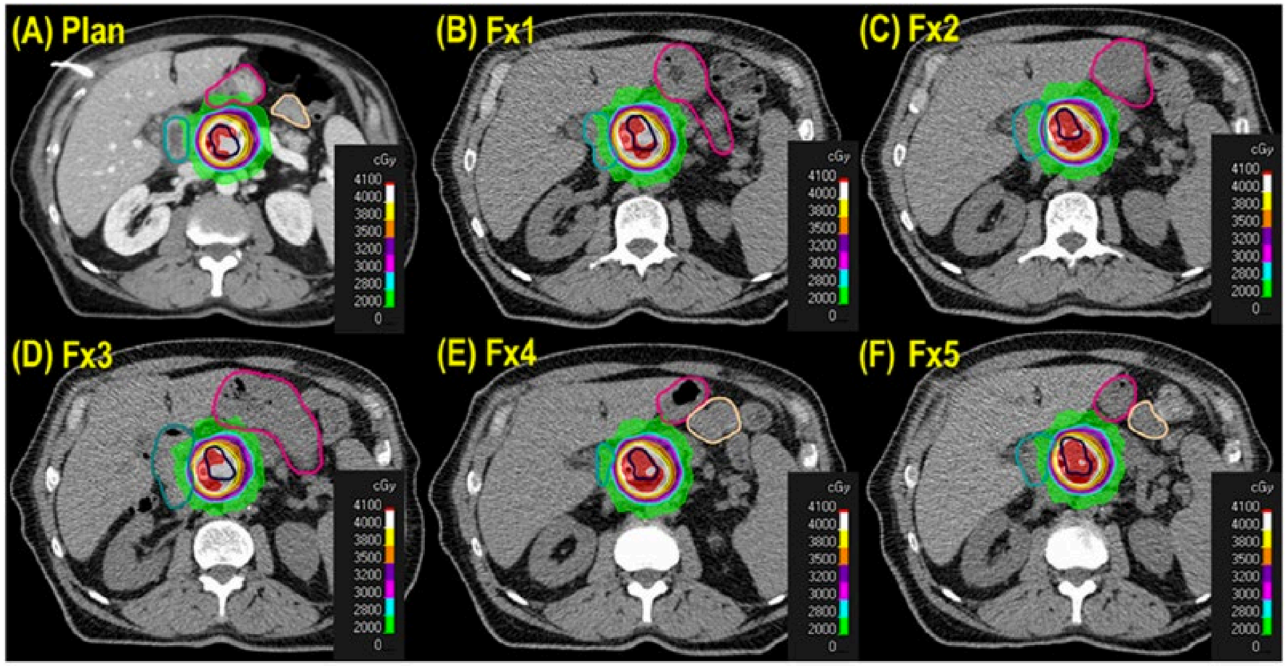
g. 3. Regions of largest displacement map of stomach_duodenum, small and large bowels between Fx1 and Fx2 for all five patien

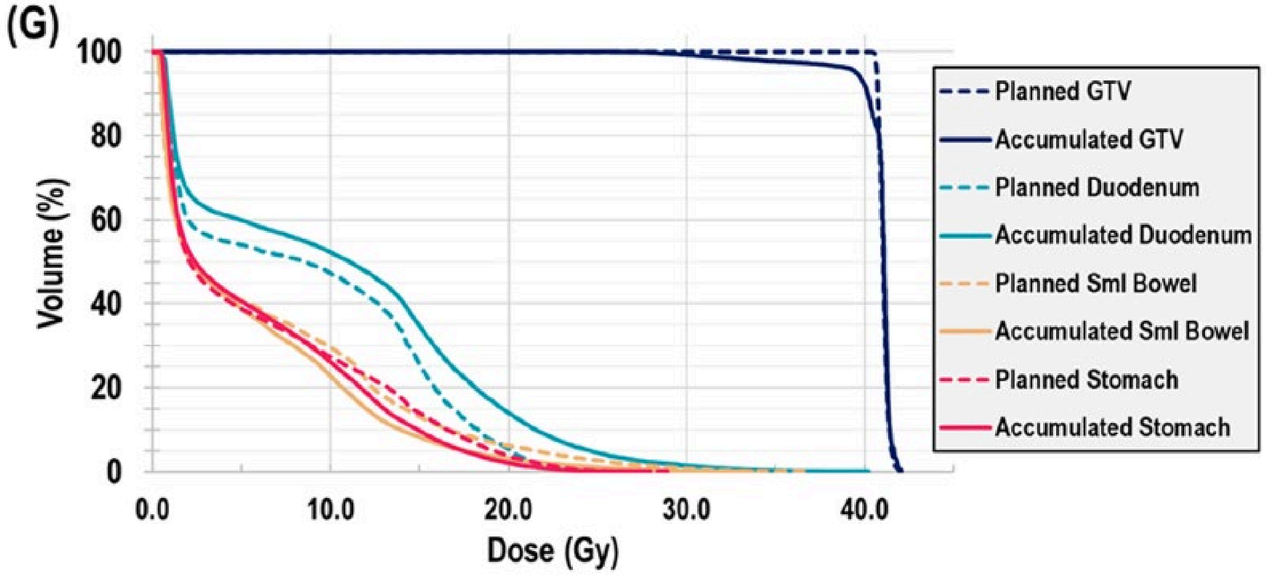
Dosimetric Uncertainties Resulting From Interfractional Anatomic Variations for Patients Receiving Pancreas Stereotactic Body Radiation Therapy and Cone Beam Computed Tomography Image Guidance

Joshua S. Niedzielski, PhD,* Yufei Liu, MD,† Sylvia S.W. Ng, MD, PhD,† Rachael M. Martin, PhD,* Luis A. Perles, PhD,* Sam Beddar, PhD,* Neal Rebueno, CMD,* Eugene J. Koay, MD, PhD,† Cullen Taniguchi, MD, PhD,† Emma B. Holliday, MD,† Prajnan Das, MD, MS,† Grace L. Smith, MD, PhD,† Bruce D. Minsky, MD,† Ethan B. Ludmir, MD,† Joseph M. Herman, MD, MSc,† Albert Koong, MD, PhD,† and Gabriel O. Sawakuchi, PhD*,‡

Int J Radiation Oncol Biol Phys, Vol. 111, No. 5, pp. 1298–1309, 2021







- Interfractional variations of organs (detected by CT-on-rail, simulation) ->
- Violations OAR constraints
- CBCT based on fiducial alignment alone does not provide adequate information regarding luminal organs

Assessing organ at risk position variation and its impact on delivered dose in kidney SABR

Gaudreault et al. Radiation Oncology (2022) 17:112
https://doi.org/10.1186/s13014-022-02041-2

Mathieu Gaudreault[1,2*], Shankar Siva[2,3], Tomas Kron[1,2] and Nicholas Hardcastle[1,2,4]

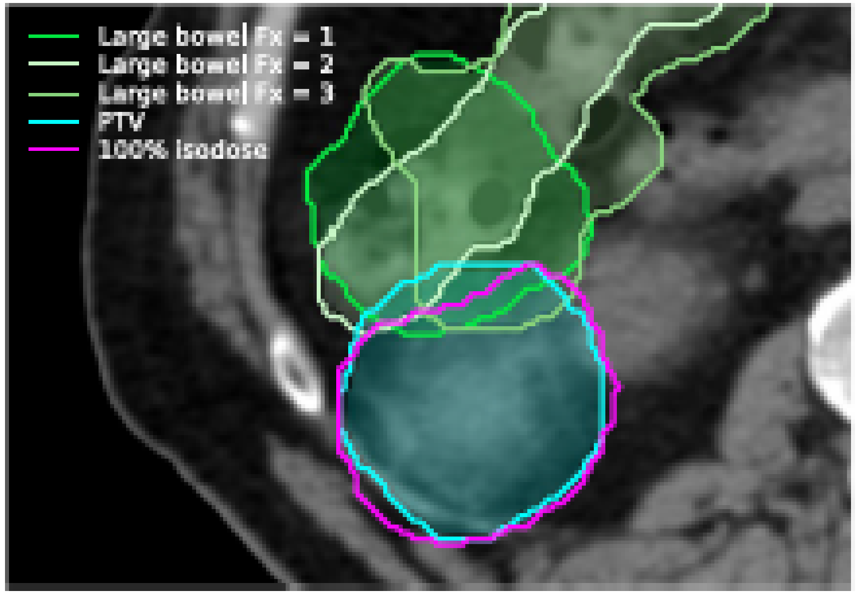


Fig. 5 Large bowel (green) position as determined from PRE CBCT in fraction 1/2/3 of a patient that had bowel stricture surgery post SABR treatment. The PTV (cyan) and the 100% isodose line (magenta) are shown

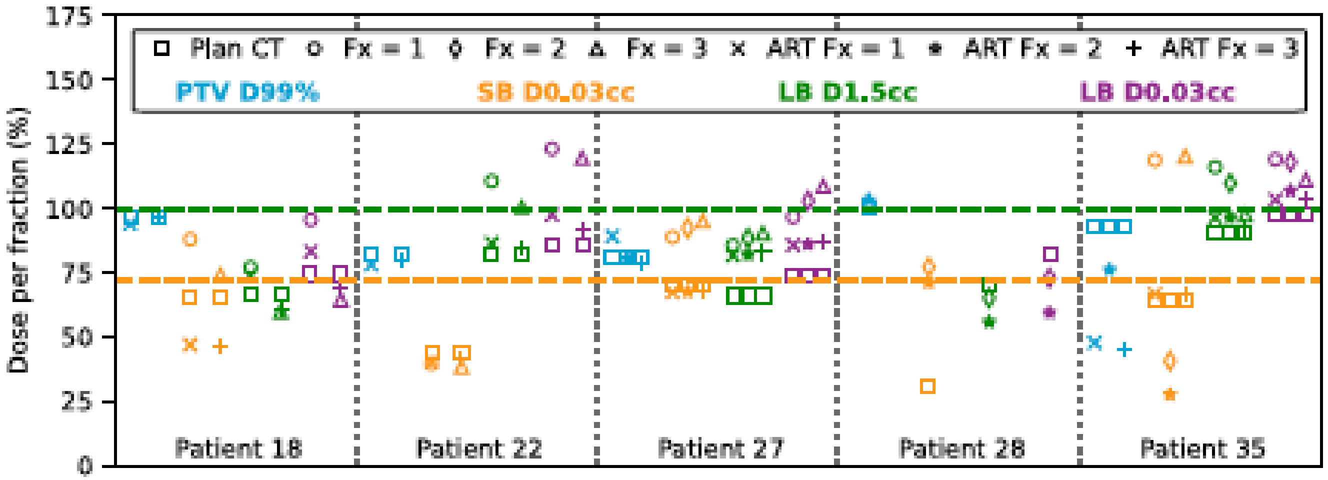


Fig. 4 Planned dose metrics per fraction PTV D99%, SB D0.03cc, LB D1.5cc and LB D0.03cc at fraction 1/2/3 for patients where a dose limit was exceeded. Results from the planned dose projected on PRE CBCTs and from ART re-optimization are shown. Orange and green dashed line indicate dose limit to the small and large bowel, respectively

- interfractional variations of organs ->
- violations OAR constraints
- large bowel strictures
- respect/adapt dose regarding to anatomy of the day!
- 3D soft tissue based imaging needed

Tanaka et al. Radiation Oncology (2022) 17:136
https://doi.org/10.1186/s13014-022-02107-1

Effect of stomach size on organs at risk in pancreatic stereotactic body radiotherapy

Osamu Tanaka[1*], Takuya Taniguchi[1], Kousei Adachi[1], Shuto Nakaya[1], Takuji Kiryu[1], Akira Ukai[2], Chiyoko Makita[3] and Masayuki Matsuo[3]

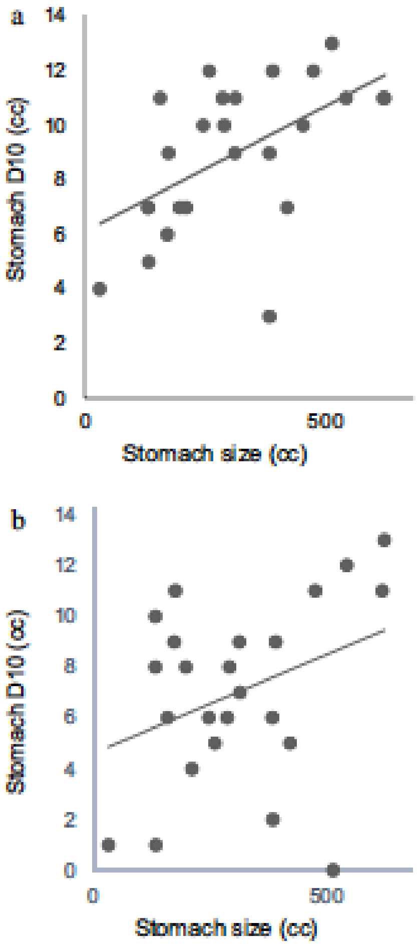


Fig. 2 **a** Correlation between stomach size and D10 (cc) to the stomach in stereotactic body radiotherapy (SBRT) for pancreatic body tumors r = 0.5516. **b** Correlation between stomach size and D10 (cc) to the stomach in SBRT for pancreatic head tumors r = 0.3499

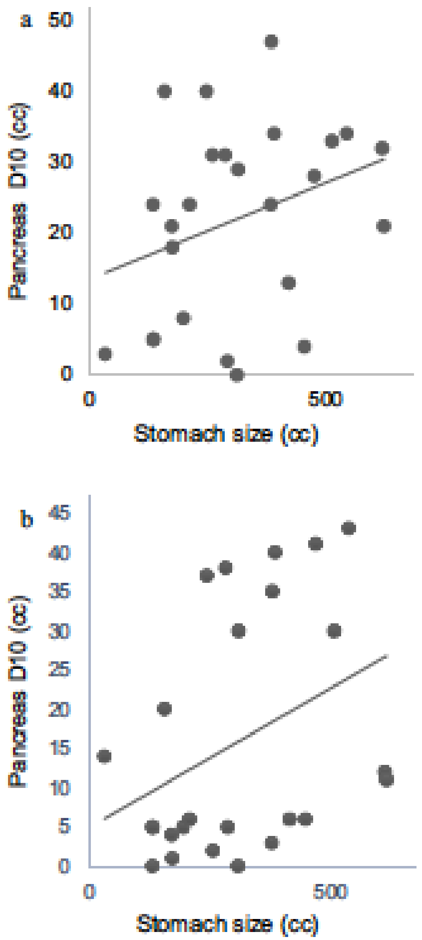
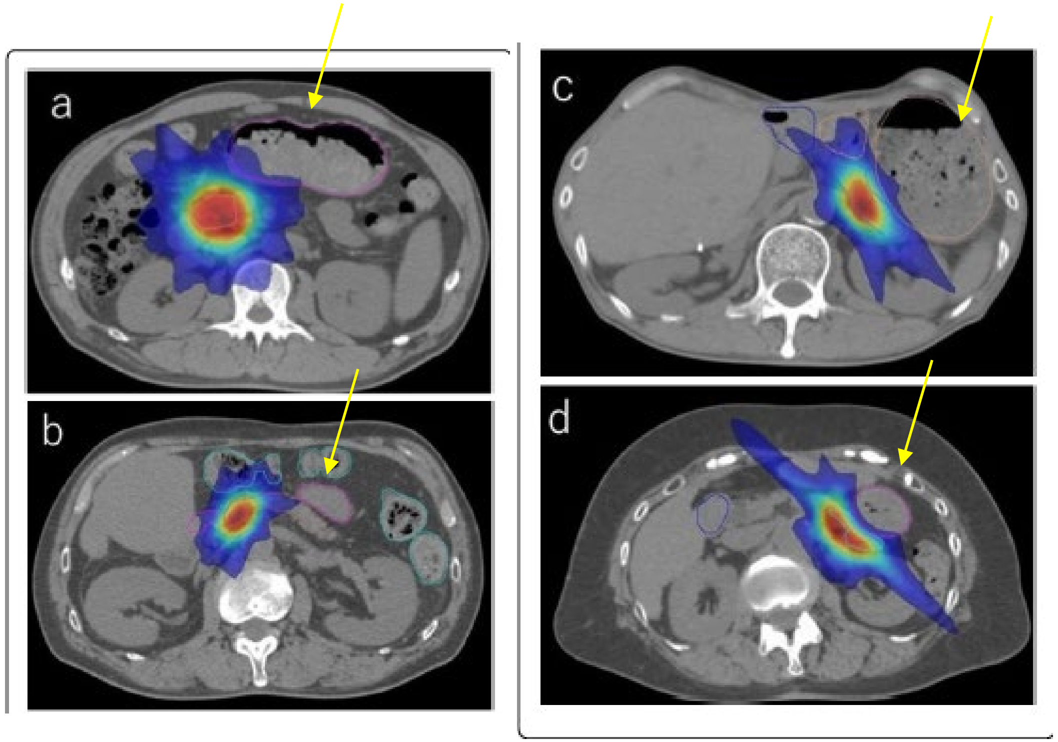


Fig. 3 **a** Correlation between stomach size and D10 (cc) to the pancreas in SBRT for pancreatic body tumors r = 0.3209. **b** Correlation between stomach size and D10 (cc) to the pancreas in SBRT for pancreatic head tumors r = 0.3679



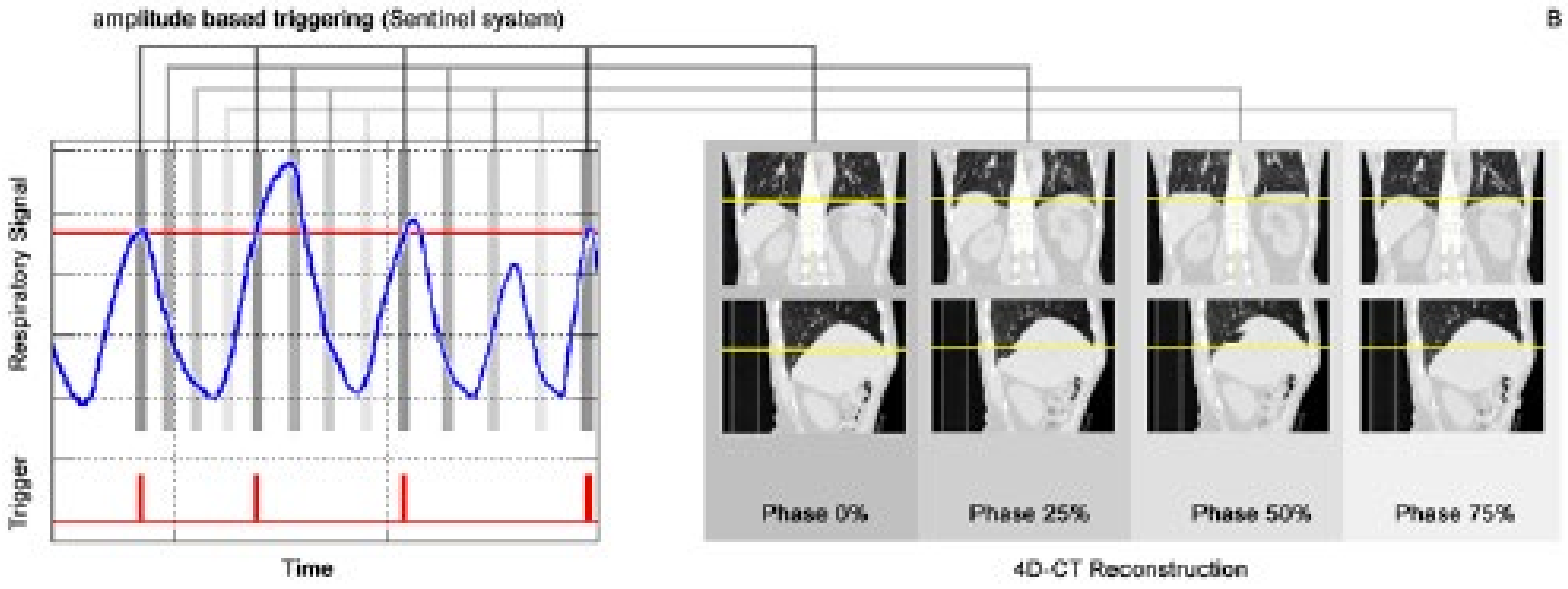
- institutional protocols
- Empty stomach
- RT in the morning

Motion estimation - 4DCT

JOURNAL OF APPLIED CLINICAL MEDICAL PHYSICS, VOLUME 16, NUMBER 2, 2015

Technical evaluation of different respiratory monitoring systems used for 4D CT acquisition under free breathing

Christian Heinz,[a] Michael Reiner, Claus Belka, Franziska Walter, Matthias Söhn



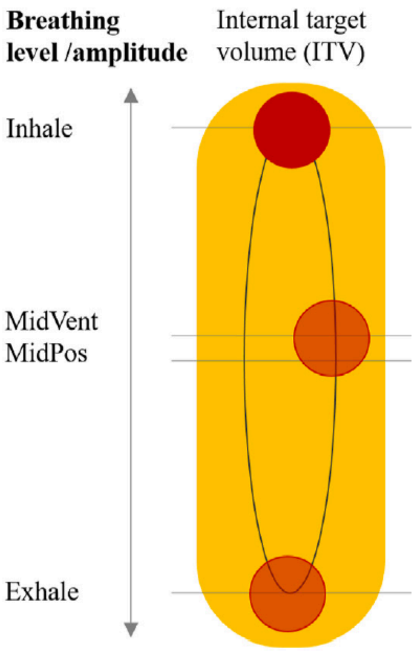


Image-guided Radiotherapy to Manage Respiratory Motion: Lung and Liver

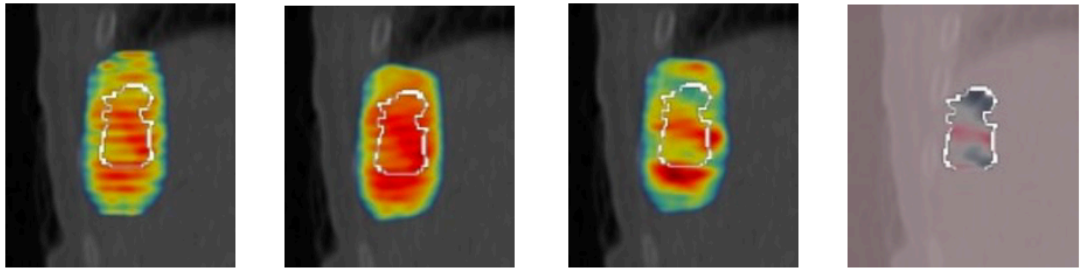
J. Dhont *†1, S.V. Harden ‡1, L.Y.S. Chee ‡, K. Aitken §¶, G.G. Hanna ‡||, J. Bertholet §**††

Breathing-motion induced interplay effects for stereotactic body radiotherapy of liver tumours using flattening-filter free volumetric modulated arc therapy

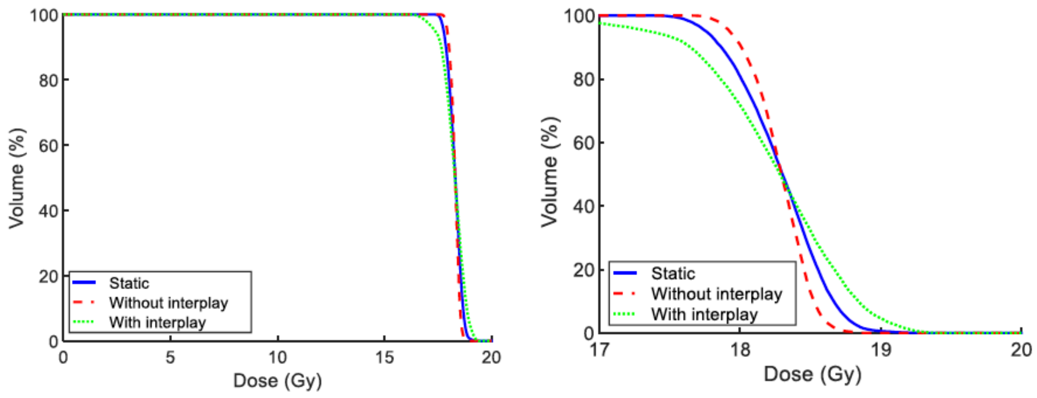
Phys. Med. Biol. 64 (2019) 025006 (11pp)

A Edvardsson[1], J Scherman[2], M P Nilsson[2,3], B Wennberg[4], F Nordström[5,6], C Ceberg[1] and S Ceberg[1]

					p-values			
						Pair-wise comparisons		
Parameter	Static	Without interplay	With interplay	Difference between with and without interplay (%)	All	Without interplay versus static	With interplay versus static	With versus without interplay
$D_{98\%}$ (Gy)	17.36 (17.01–17.63)	17.46 (15.68–17.82)	17.05 (15.71–17.36)	−2.1 (−5.0–0.2)	0.007*	0.275	0.004*	0.006*
D_{mean} (Gy)	18.09 (17.80–18.35)	18.05 (17.77–18.27)	18.05 (17.62–18.24)	−0.1 (−1.0–0.5)	0.020*	0.014*	0.027	0.770
HI (%)	7.3 (6.2–9.9)	6.2 (4.7–16.1)	12.2 (7.1–17.9)	72.2 (11.0–150.5)	<0.001*	0.084	0.002*	0.002*



a) b) c) d)



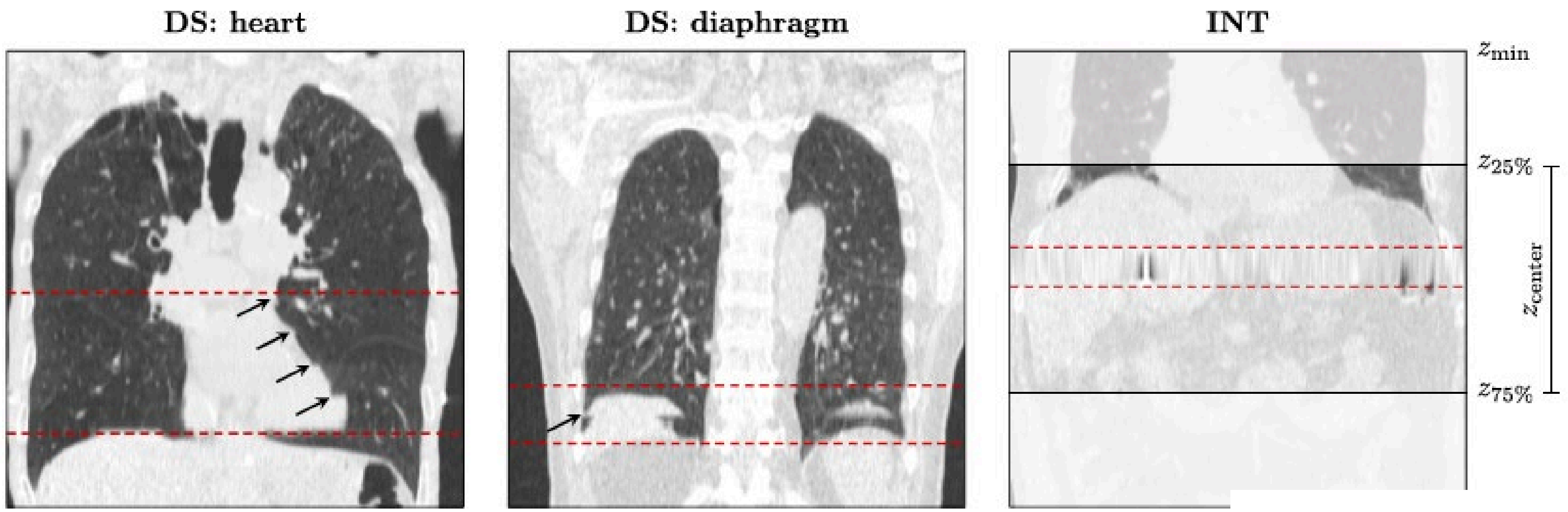
e) f)

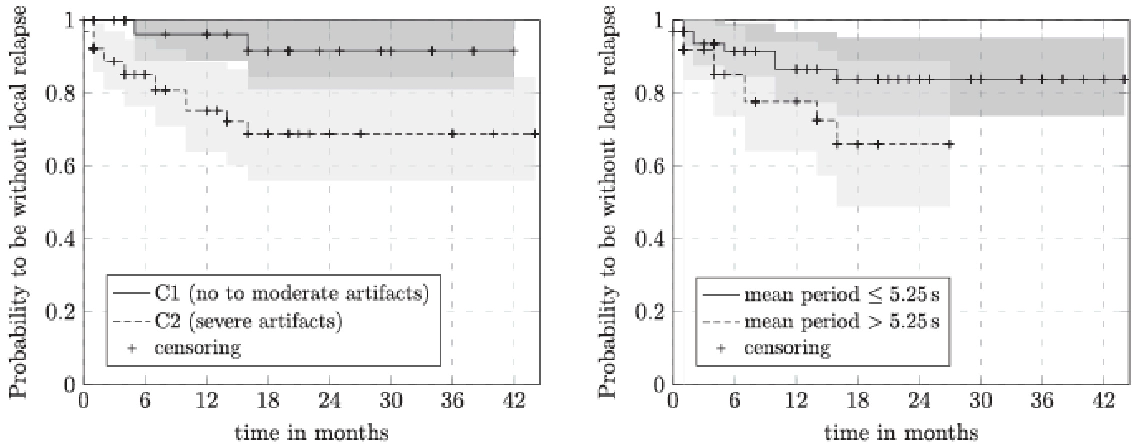
- sign. breathing-induced interplay effects
- -> heterogenous dose distribution (GTV)
- clinical impact has to be further investigated

Radiotherapy and Oncology 148 (2020) 229–234

4D CT image artifacts affect local control in SBRT of lung and liver metastases

Thilo Sentker [a,c,*,1], Vladimir Schmidt [a,1], Ann-Kathrin Ozga [b], Cordula Petersen [a], Frederic Madesta [c], Christian Hofmann [d], René Werner [c,2], Tobias Gauer [a,2]





number at risk									number at risk								
C1	38	25	24	18	11	7	3	1	**≤ 5.25 s**	65	45	35	28	20	14	10	4
C2	64	43	27	18	11	7	7	3	**> 5.25 s**	37	23	16	8	2	0	0	0

Motion reduction - Abdominal compression

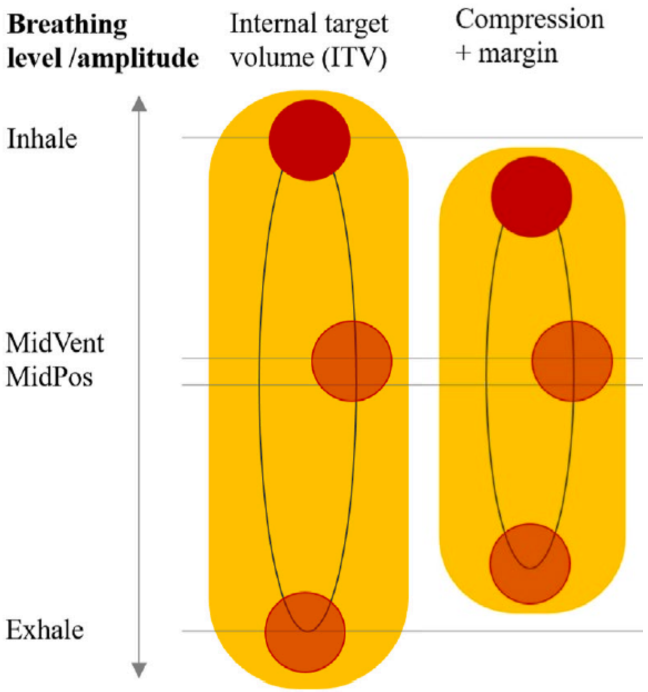


Image-guided Radiotherapy to Manage Respiratory Motion: Lung and Liver

J. Dhont [*†1], S.V. Harden [‡1], L.Y.S. Chee [‡], K. Aitken [§¶], G.G. Hanna [‡||], J. Bertholet [§**††]

ACTA ONCOLOGICA
2022, VOL. 61, NO. 7, 833–841
https://doi.org/10.1080/0284186X.2022.2073186

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ORIGINAL ARTICLE

OPEN ACCESS Check for updates

Radiotherapy respiratory motion management in hepatobiliary and pancreatic malignancies: a systematic review of patient factors influencing effectiveness of motion reduction with abdominal compression

Mairead Daly[a], Alan McWilliam[a,b], Ganesh Radhakrishna[b], Ananya Choudhury[a,b] and Cynthia L. Eccles[a,b]

Table 2. Overview of included studies including choice of abdominal compression (AC) device, number of includ

Reference	Study design	N (site)
Wunderink, 2008 [33]	Prospective non-randomised, non-blinded	12 Liver (10 metastases, 2 HCC)
Eccles, 2011 [35]	Prospective non-randomised (part of Phase I/II study)	60 Liver (30 metastases, 24 HCC, 6 CCA)
Lovelock, 2014 [43]	Retrospective non-randomised, non-blinded	42 (30 liver, 6 adrenal, 3 pancreas, 3 nodes)
Heerkens, 2017 [34]	Prospective non-randomised (part of Phase II feasibility trial)	10 Pancreas, (9 LAPC, 1 refused surgery) (8 head, 2 tail)
Van Gelder, 2018 [44]	Retrospective non-randomised, non-blinded	15 (13 Liver, 2 pancreas)
West, 2018 [45]	Retrospective non-randomised, non-blinded	13 (12 liver, 1 kidney)

HCC: hepatocellular carcinoma; CCA: cholangiocarcinoma.

Table 3. Changes in craniocaudal (CC) motion amplitude with and without abdominal compression (AC) for studies included in this systematic review.

	Reference	Measurement method	Measurement Point	CC Motion Without AC	CC Motion With AC
Arch	Wunderink, 2008 [33]	Fluoroscopy	Fiducial markers	Mean 10.8 mm Range 4.4–25.3 mm	Mean 4.2 mm Range 1.7–8.5 mm
	Eccles, 2011 [35]	T2-weighted cine-MRI	Tumour	Mean 11.7 mm Range 4.8–23.3 mm	Mean 9.4 mm Range 1.6–23.5 mm
Belt	Lovelock, 2014 [43]	Fluoroscopy	Surgical clips or Fiducial markers	Mean 11.4 mm Range 5–20 mm	Mean 4.4 mm Range 1–8 mm
	Heerkens, 2017 [34]	T2-weighted Cine MRI, 4DCT	Tumour	Mean 11.3 mm Range 7.5 – 22.1 mm	Mean 7.2 mm Range 4.1 – 12.1 mm
	Van Gelder, 2018 [44]	4DCT	Liver dome	Mean 8.7 ± 3.0 mm	Mean 8.0 ± 3.8 mm
	West, 2018 [45]	4DCT	Right diaphragm	Median: 12.0 ± 4.4 mm	Median: 8.0 ± 5.1 mm

Motion reduction (mean CC): 0.7 – 6.6mm

Motion increase (!) LR 1.6mm

Anti-anxiety medication in 2 studies (!)

- 6 studies
- AC reduces CC motion, however….
- resp. motion is patient-specific ->
- patient-specific MM strategies are required (AC not effective/ appropriate for all)
- effectiveness affected by BMI
- in cases of small motion (<5mm), benefit <-> increased motion and discomfort
- alternative methods should be considered if available (BH)
- monitoring during delivery is essential
- studies needed…

Transmission study of the Abdominal Compression plate (BodyFIX Diaphragm Control) for abdominal and stereotactic body radiotherapy

J Appl Clin Med Phys. 2021;22:232–241.

Hema Vaithianathan | Benjamin Harris

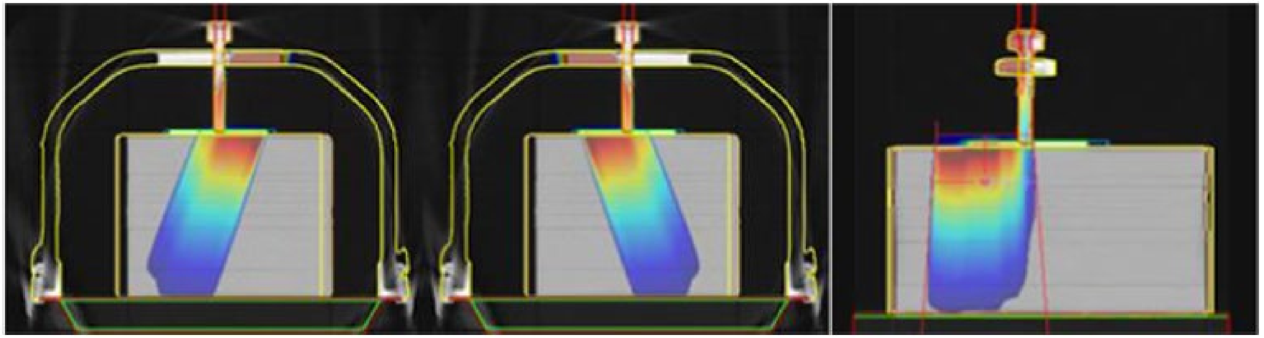


FIGURE 4 Beam arrangement through G20 (left) and G340 (centre), and (right) a sagittal view through the compression plate alone, offset 4 cm superior to the fixation screw centre

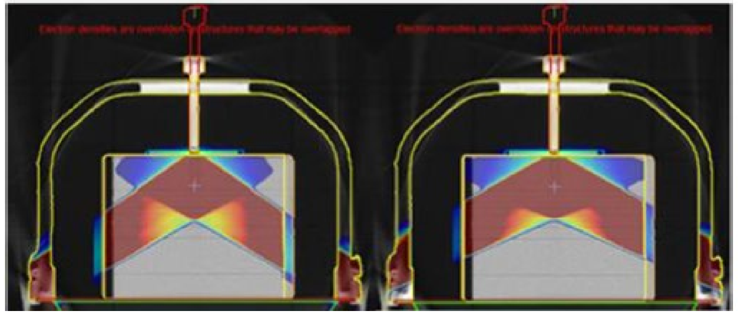


FIGURE 7 Beam arrangement through the couch fixation region for beams aligned with the centre of the fixation screw (left) and offset 3.2 cm superiorly (right) to cover the region's high density variations

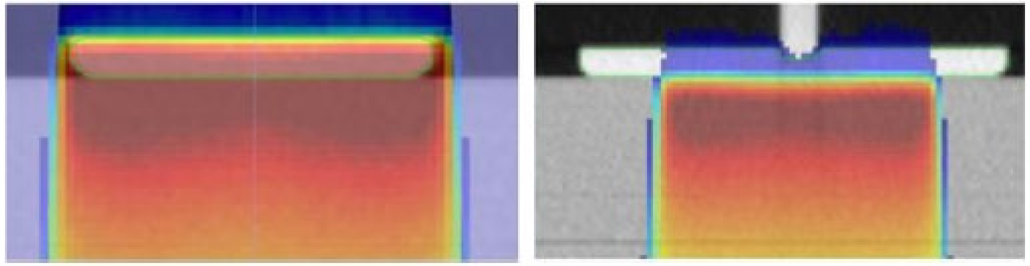


FIGURE 8 Demonstration of TPS skin dose calculations (6 MV photon beam), with the compression plate in place (left) and with the plate density overridden to air (right)

- AC can cause signif. dose attenuation
- Density overrides are recommended for correcting attenuations
- High-density stuctures (screw; frame fixation points) create high levels of dosimetric uncertainity
- No beam entry through those areas!

Fiducials/Surrogates

AME Case Rep 2021;5:15 | http://dx.doi.org/10.21037/acr-20-153

Fiducial marker migration following computed tomography-guided placement in the liver: a case report

Karishma Khullar[1], Survandita Tara Dhawan[2], John Nosher[3], Salma K. Jabbour[1]

Figure 1 Fiducial migration into the inferior vena cava. (A) Scan shows twin fiducial placemer following fiducial placement shows one fiducial marker in the liver. (C) Scan shows fiducial migra vein and inferior vena cava as denoted by the arrow.

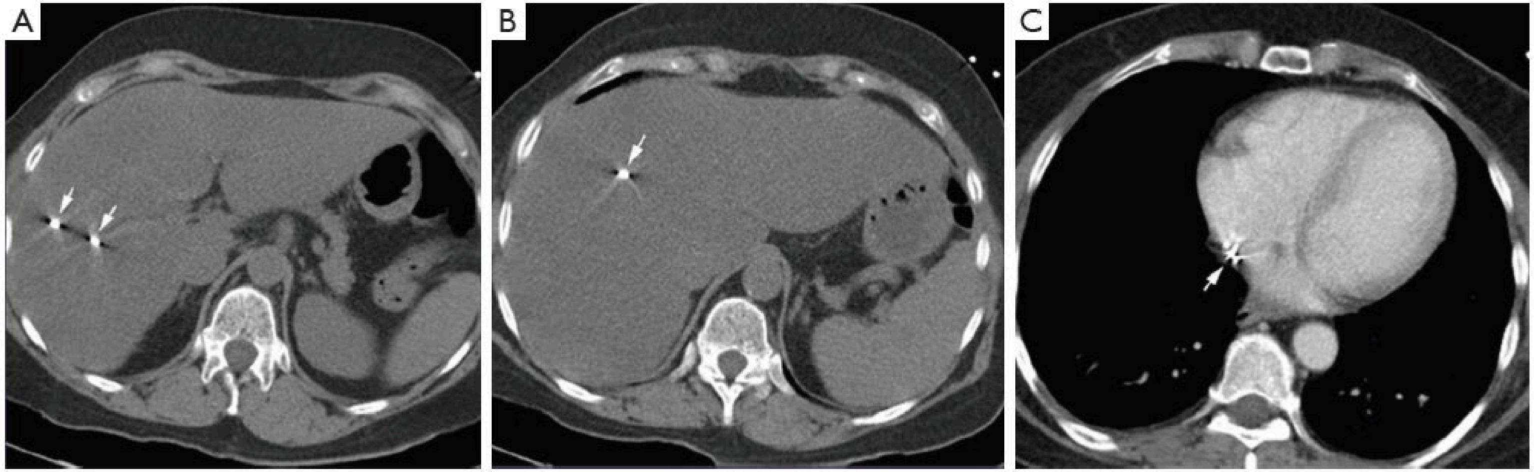


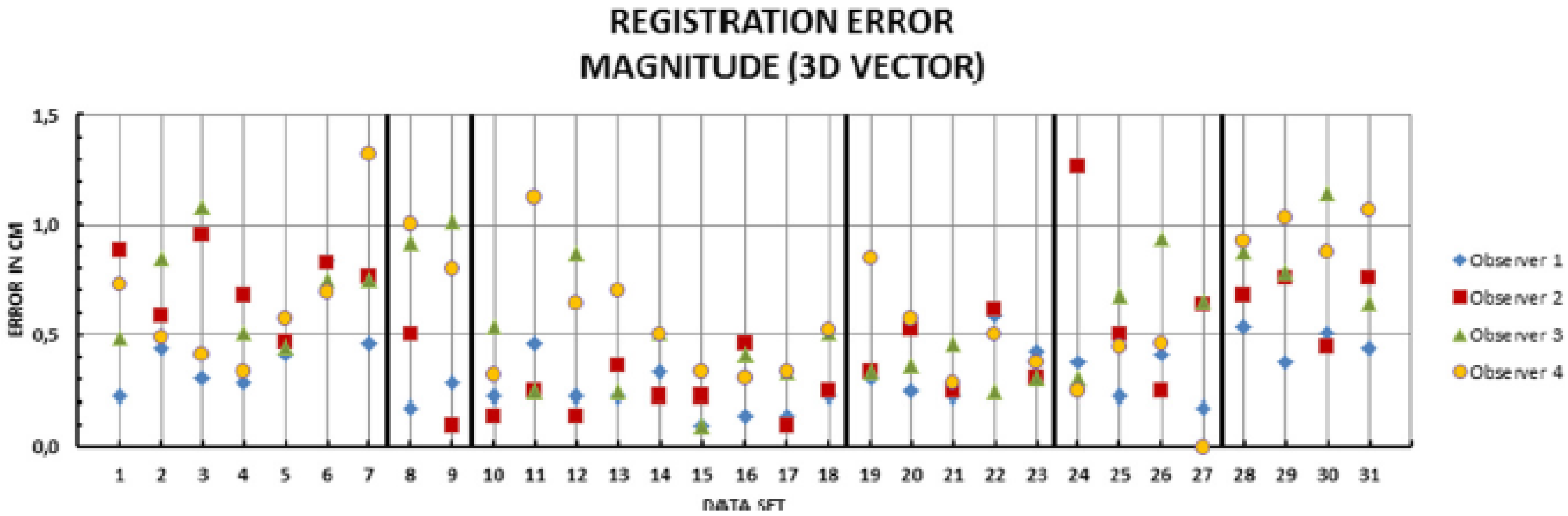
Figure 2 Fiducial migration into the right atrium. (A) Scan shows twin fiducial placement into the right lobe of the liver. (B) Scan following fiducial placement shows one fiducial marker in the liver. (C) Scan of the lower chest shows fiducial at junction of inferior vena cava and right atrium.

- Institutional marker migration rate 5% (New Yersey, USA)
- No tox detected

Feasibility study on image guided patient positioning for stereotactic body radiation therapy of liver malignancies guided by liver motion

Christian Heinz[*†], Sabine Gerum[†], Philipp Freislederer, Ute Ganswindt, Falk Roeder, Stefanie Corradini, Claus Belka and Maximilian Niyazi

Fig. 1 a example of a registration based on fiducial markers (*green*); **b** Example of a registration based on the organ motion of the liver (*red*) displayed at different window/level settings



- rigid registration not accurate enough (based on internal liver target volume)
- blurred fiducial markers (IMTV)
- individual registration errors up to 1.3cm
- error due to non-rigid changes
- fiducials next to the target

Investigation of tumor and vessel motion correlation in the liver

J Appl Clin Med Phys 2020; 21:8:183–190

Sydney A. Jupitz[1] | Andrew J. Shepard[2] | Patrick M. Hill[2] | Bryan P. Bednarz[1]

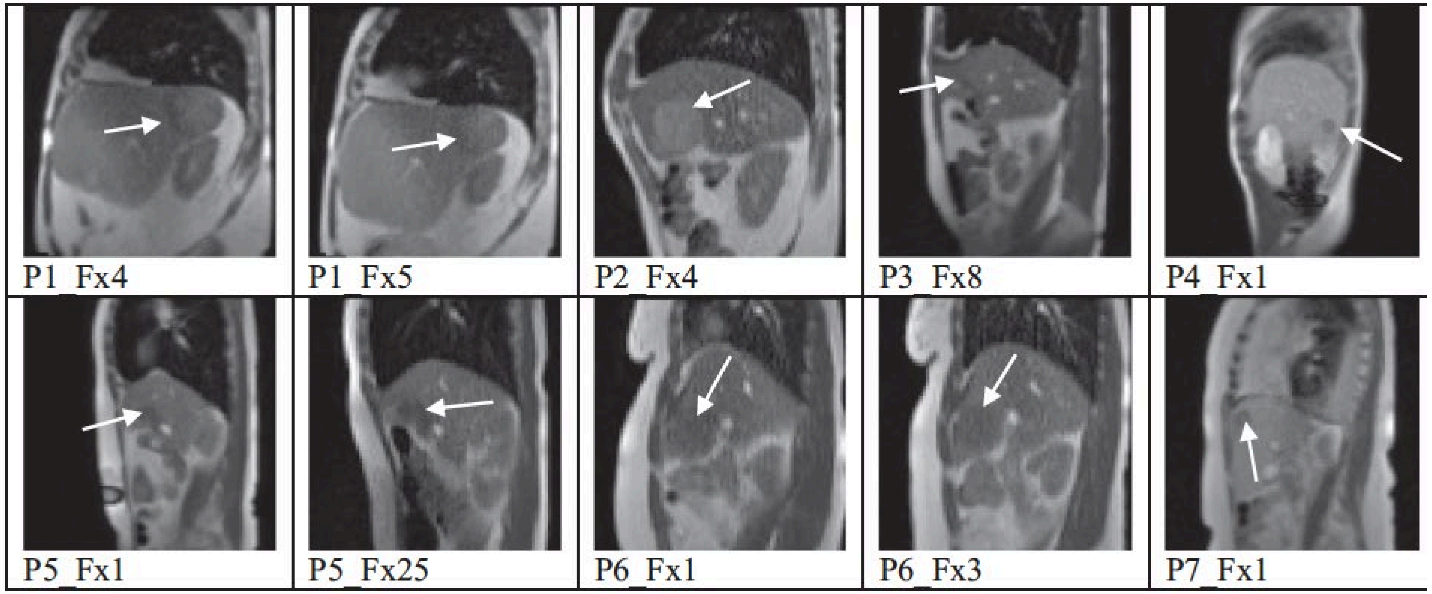
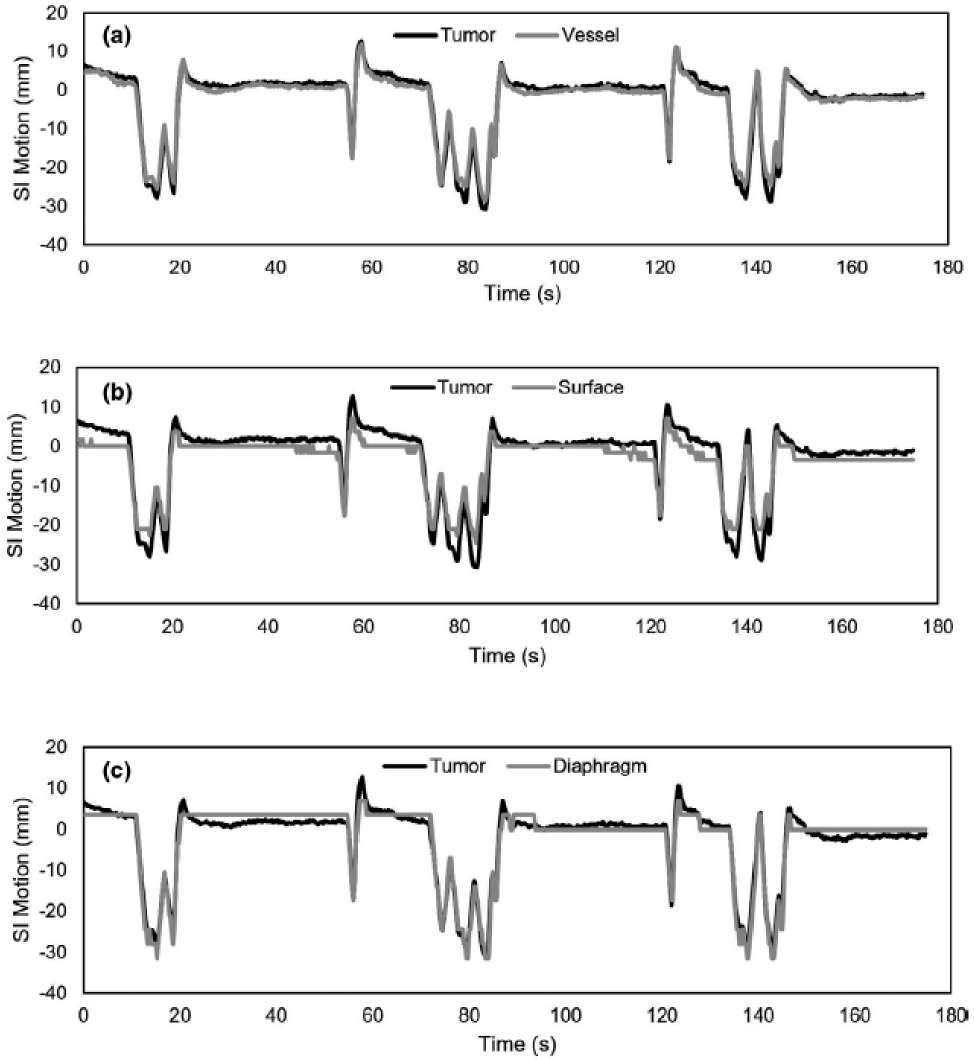


FIG. 1. Patients and tumor locations, indicated by the white arrow, within the liver.

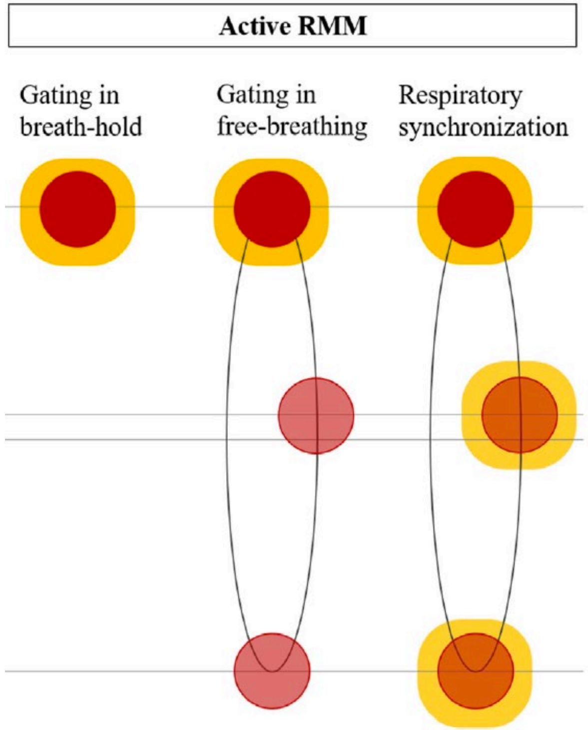


- Tumor motion correlated with surface, vessel and diaphragm motion
- Tumor motion can be captured with a direct relationship to vessel motion (intrafract variability analysis)
- DD and vessels are suitable surrogates

- Other surrogates (coils, clips, lipiodol…)

„Removing“ breathing motion

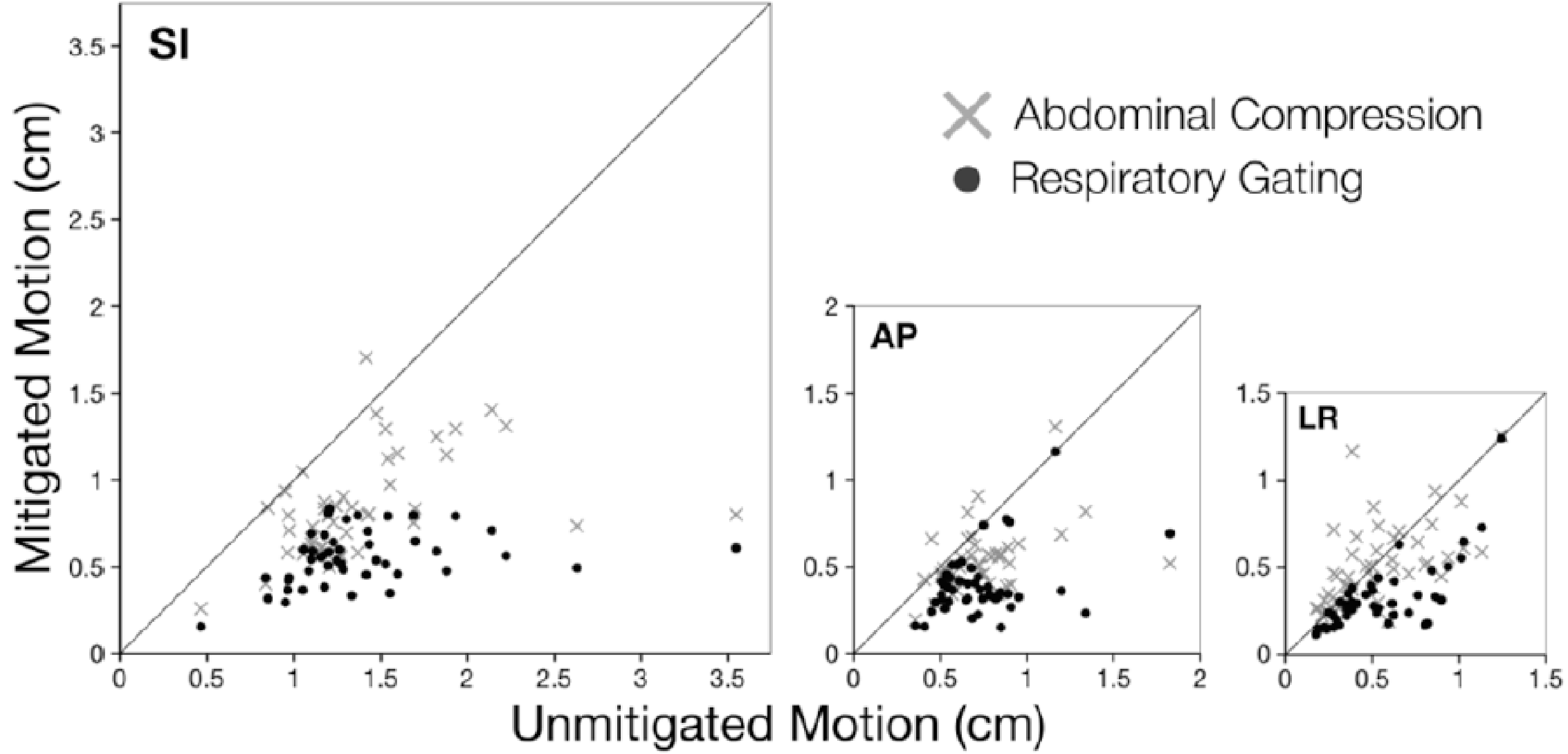
- Breath hold (DIBH/ DEBH)
- Gating
- Tracking

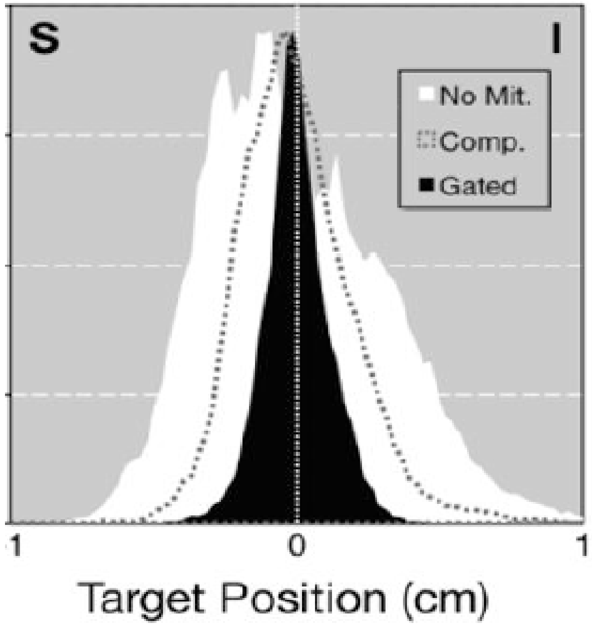


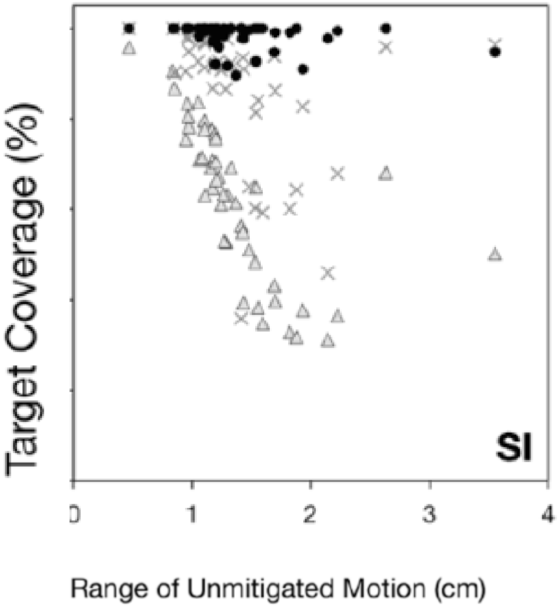
An evaluation of motion mitigation techniques for pancreatic SBRT

Radiother Oncol. 2017 July ; 124(1): 168–173. doi:10.1016/j.radonc.2017.05.013.

Warren G. Campbell, **Bernard L. Jones**, **Tracey Schefter**, **Karyn A. Goodman**, and **Moyed Miften**







- AC reduced AP and CC motion (by 27% and 39%)
- gating however signif. better (reduction AP 47%, CC 60%)
- resp. Gating most effective strategy

Clinical impact of removing respiratory motion during liver SABR

Gargett *et al. Radiation Oncology* (2019) 14:93

M. Gargett[1*], C. Haddad[1], A. Kneebone[1], J. T. Booth[1,2] and N. Hardcastle[2,3]

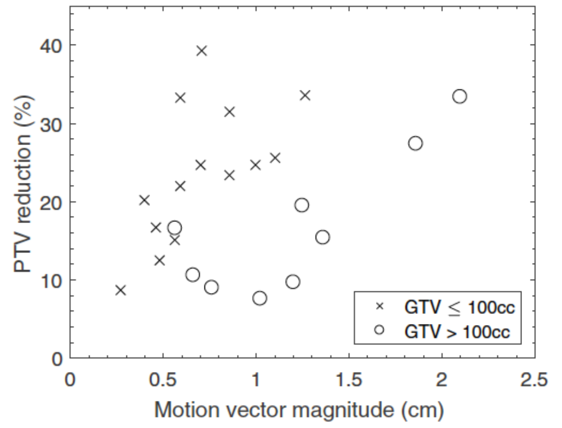
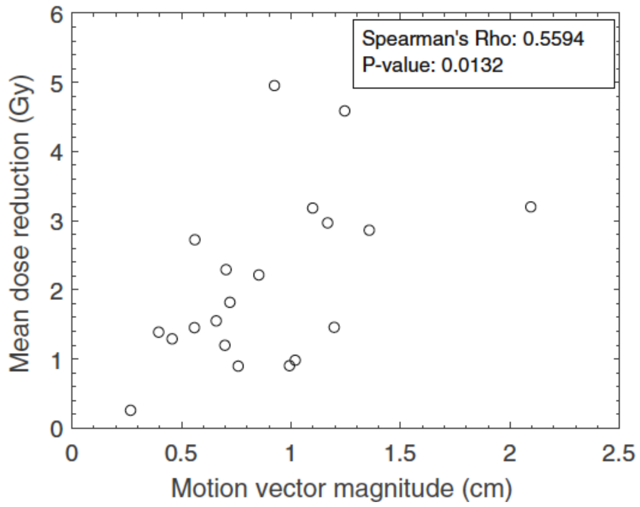


Fig. 3 PTV reduction as a function of the magnitude of the motion vector of the centre of mass of the GTV. PTV reduction is presented as the difference in motion managed and ITV-based PTV sizes, as a percentage of the ITV-based PTV size



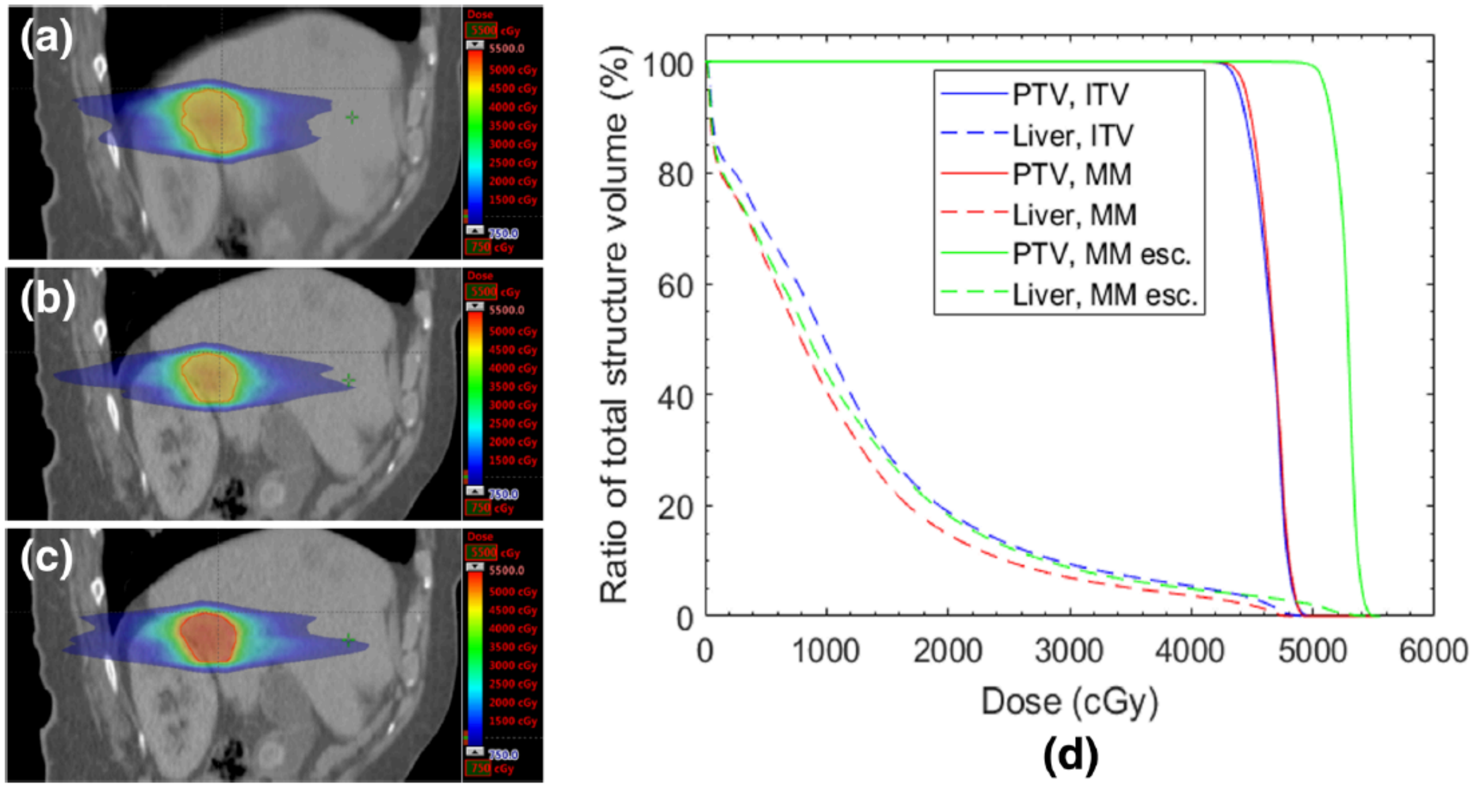


Fig. 6 Part (**a**) shows the dose distribution to a lesion planned using the ITV method. Part (**b**) shows the re-plan using the motion managed PTV, at the same prescription level as in (**a**). Part (**c**) shows the escalation of dose, from 42.5 Gy to 50 Gy (78.6 Gy_{10} to 100 Gy_{10}), whilst adhering to OAR dose tolerances. Part (**d**) is a DVH demonstating PTV coverage (solid lines) for the three cases shown in (**a**) – (**c**), as well as liver dose (broken lines). ITV – ITV-based, MM – motion managed, MM esc – dose escalated motion management

Eliminating resp. motion ->
PTV dose escalation, TCP-increase, reduction of Dmean Liver

Reducing the impact on renal function of kidney SABR through management of respiratory motion

Physica Medica 89 (2021) 72–79

Mathieu Gaudreault [a,b,*], Shankar Siva [b,c], Tomas Kron [a,b,d], Nicholas Hardcastle [a]

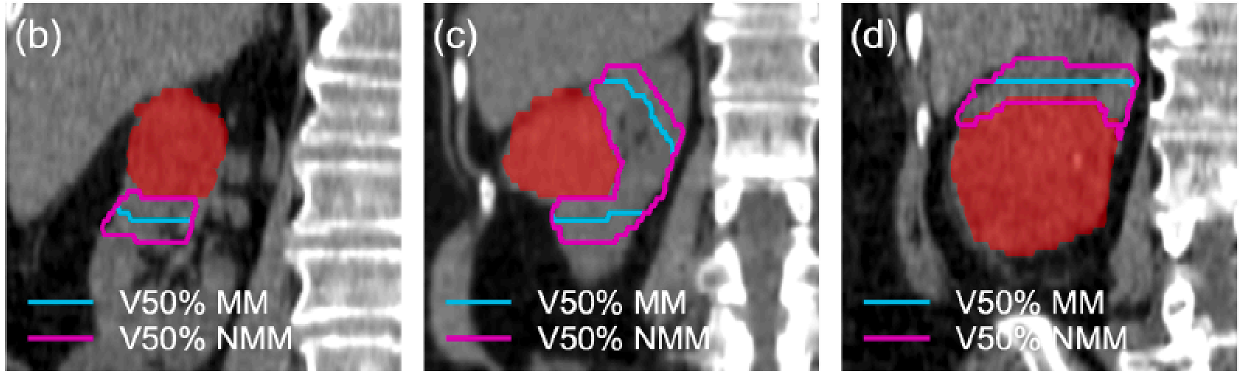
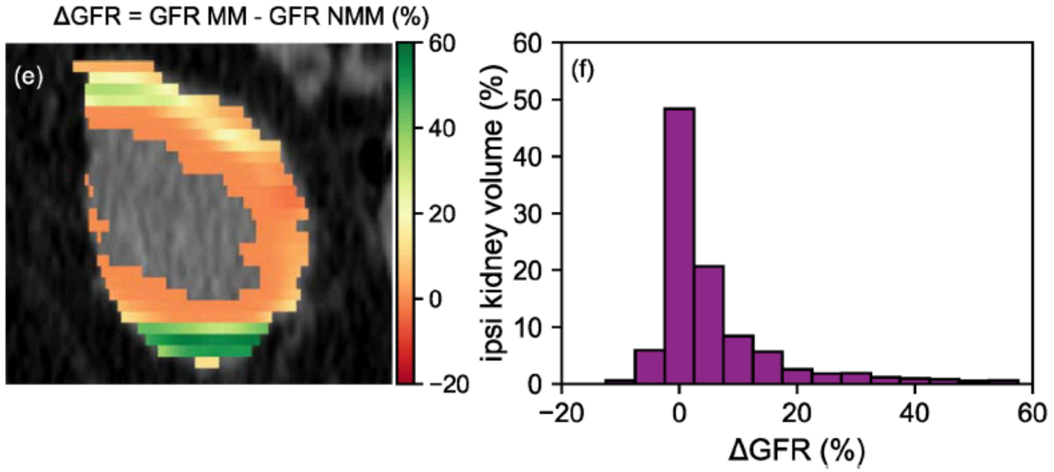


Fig. 3. (a) Non-tumour ipsilateral kidney V50% difference between MM plan and NMM plan (cc) as a function of the tumour motion amplitude (cm). Linear fit on upper pole (orange, dashdot), interpolar (yellow, dashed), and lower pole (purple, dotted) are shown. Examples of V50% resulting from MM plan (cyan) and NMM plan (magenta) and the GTV (red) are shown for the (b) upper pole, (c) interpolar, and (d) lower pole tumour location. (For interpretation of the references to colour



-> kidney tissue sparing
-> GFR gain of 4.4%/cm motion removed

Accuracy and efficiency of respiratory gating comparable to deep inspiration breath hold for pancreatic cancer treatment

J Appl Clin Med Phys 2021; 22:1:218–225

Chuan Zeng[1] | Xiang Li[1] | Wei Lu[1] | Marsha Reyngold[2] | Richard M. Gewanter[2] | John J. Cuaron[2] | Ellen Yorke[1] | Tianfang Li[1]

Table 5 Comparison of motion characteristics and treatment time of all patients.

Parameter	DIBH	RG
Residual motion over the whole course / mm Mean (range)	6 (3–8)[a]	6 (4–10)[a]
Mean magnitude of displacement* in one fraction / mm Range	0–5[a]	0–6[a]
Mean magnitude of displacement* over the whole course / mm Range	0–3[a]	0–3[a]
Treatment time / min Mean ± SD	15 ± 3[a]	17 ± 4[a]

Abbreviations: DIBH, deep inspiration breath hold; RG, respiratory gating.
aP > 0.05 (two-sample t-test).

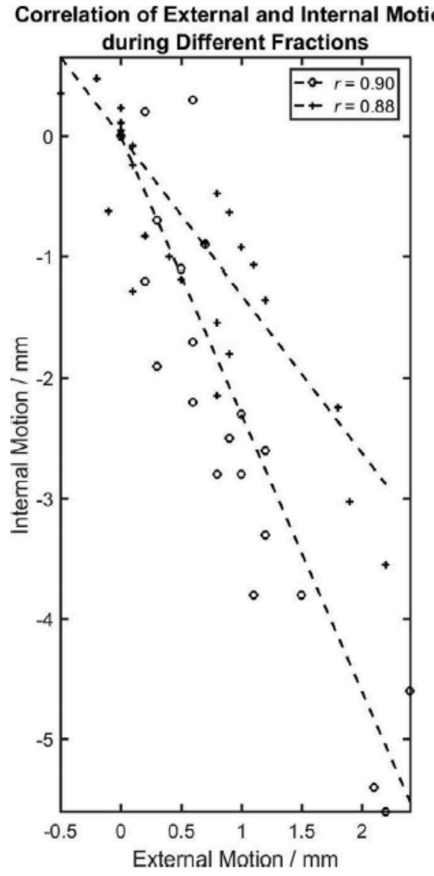


Fig. 3. The correlation of the superior-inferior motion of a fiducial marker to the external marker motion for one patient during two different respiratory-gated treatment sessions (circle 'o' and plus sign '+'). The dependence was highly linear in both fractions, as shown by the least-square linear fit (dashed lines). However, the dependence varied quantitatively by about a factor of two in slope.

- Accuracy and efficacy of RG and DIBH are comparable
- RG is a feasible alternative to DIBH

Int J Radiation Oncol Biol Phys, Vol. 111, No. 5, pp. 1289–1297, 2021

A Prospective Trial Demonstrating the Benefit of Personalized Selection Of Breath-Hold Technique for Upper-Abdominal Radiation Therapy Using the Active Breathing Coordinator

Briana Farrugia, BAppSc,*,† Kellie Knight, HScD, MHlthSc, BAppSc,†

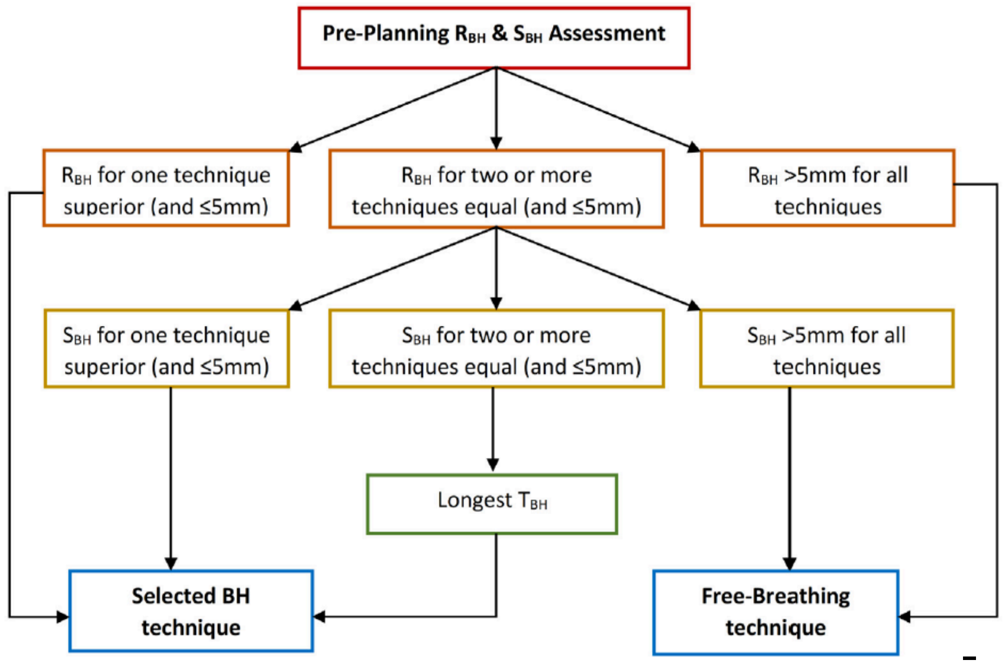


Fig. 1. Decision Matrix for personalized selection of BH technique.

Table 3 Stability and reproducibility (mm) for each breath-hold technique versus selected breath-hold technique, mean (SD)

Measure	Breath-hold technique, mean (SD)		P value
Deep inspiration breath-hold technique versus selected breath-hold technique for non-deep inspiration breath-hold selected patients (n = 15)			
Measure	DIBH	Selected BH	*P* value
Stability (mm)	2.00 (1.12)	1.29 (1.19)	.036
Reproducibility (mm)	3.12 (2.59)	0.98 (0.85)	.009
IBH vs selected BH technique, for non-IBH selected patients (n = 11)	Breath-hold Technique, mean (SD)		
Measure	IBH	Selected BH	*P* value
Stability (mm)	3.18 (2.53)	2.18 (2.50)	.005
Reproducibility (mm)	2.82 (1.95)	1.09 (0.95)	.009
EBH vs selected BH technique, for non-EBH selected patients (n = 10)	Breath-hold technique, mean (SD)		
Measure	EBH	Selected BH	*P* value
Stability (mm)	2.56 (3.52)	2.46 (2.61)	.902
Reproducibility (mm)	2.20 (1.70)	0.63 (0.29)	.011

Abbreviations: BH = breath hold; DIBH = deep inspiration breath hold; EBH = expiration breath hold.

- Preplanning screening is feasible to personalise the selection of BH technique based on kV fluoroscopy
- EBH superior regarding reproducibility

Influence of intra- and interfraction motion on planning target volume margin in liver stereotactic body radiation therapy using breath hold

https://doi.org/10.1016/j.adro.2020.10.023

Patricia A.K. Oliver, PhD,[a,*] Mammo Yewondwossen, PhD,[a,b,c] Clare Summers, RTT, Conor Shaw, PhD,[a] Slawa Cwajna, MD,[b] and Alasdair Syme, PhD[a,b,c,*]

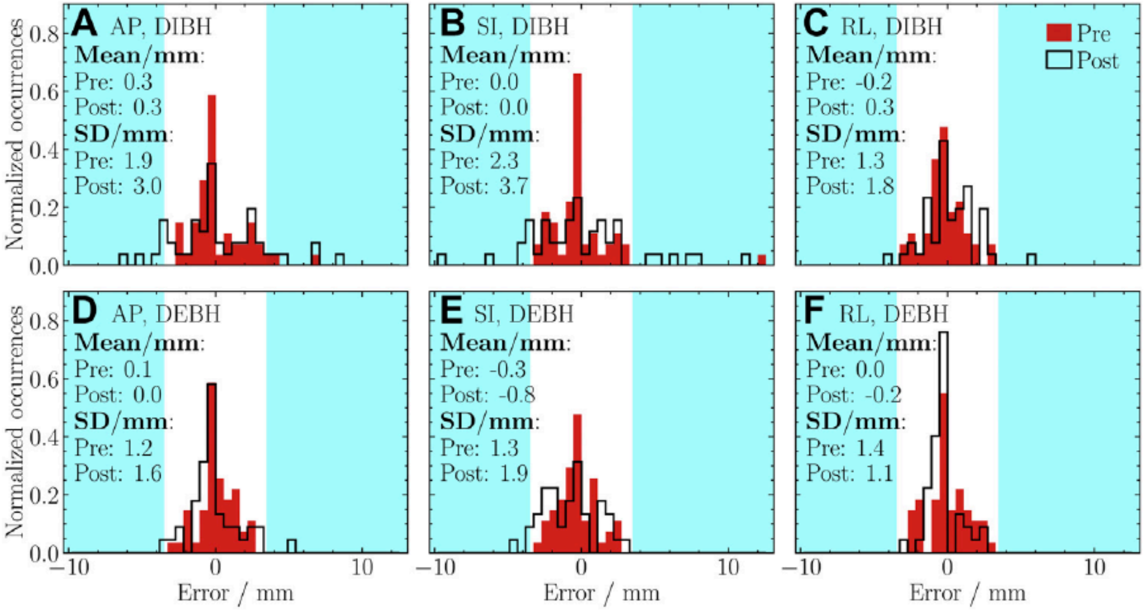


Figure 2 Distributions of pre- and posttreatment errors for (A, D) anterior–posterior, (B, E) superior–inferior, and (C, F) right–left directions. The results are presented for (A, B, C) deep inspiration breath hold and (D, E, F) deep expiration breath hold. The mean and standard deviation are indicated. Errors outside of the 3-mm tolerance are in cyan. In 3 deep inspiration breath hold treatment fractions, pretreatment errors of >3 mm were accepted by the radiation oncologist for clinical reasons.

DEBH: smaller SD of random and syst error, 1-2mm smaller margins

Study protocol of the LARK (TROG 17.03) clinical trial: a phase II trial investigating the dosimetric impact of Liver Ablative Radiotherapy using Kilovoltage intrafraction monitoring

Lee et al. BMC Cancer (2021) 21:494
https://doi.org/10.1186/s12885-021-08184-x

Yoo Young Dominique Lee[1,2*], Doan Trang Nguyen[2,3,4], Tre
Andrew Hickey[5], Nicole Pritchard[5,8], Per Poulsen[9], Elizaveta M
David Pryor[1], Julie Chu[10], Nicholas Hardcastle[1], Jeremy Booth

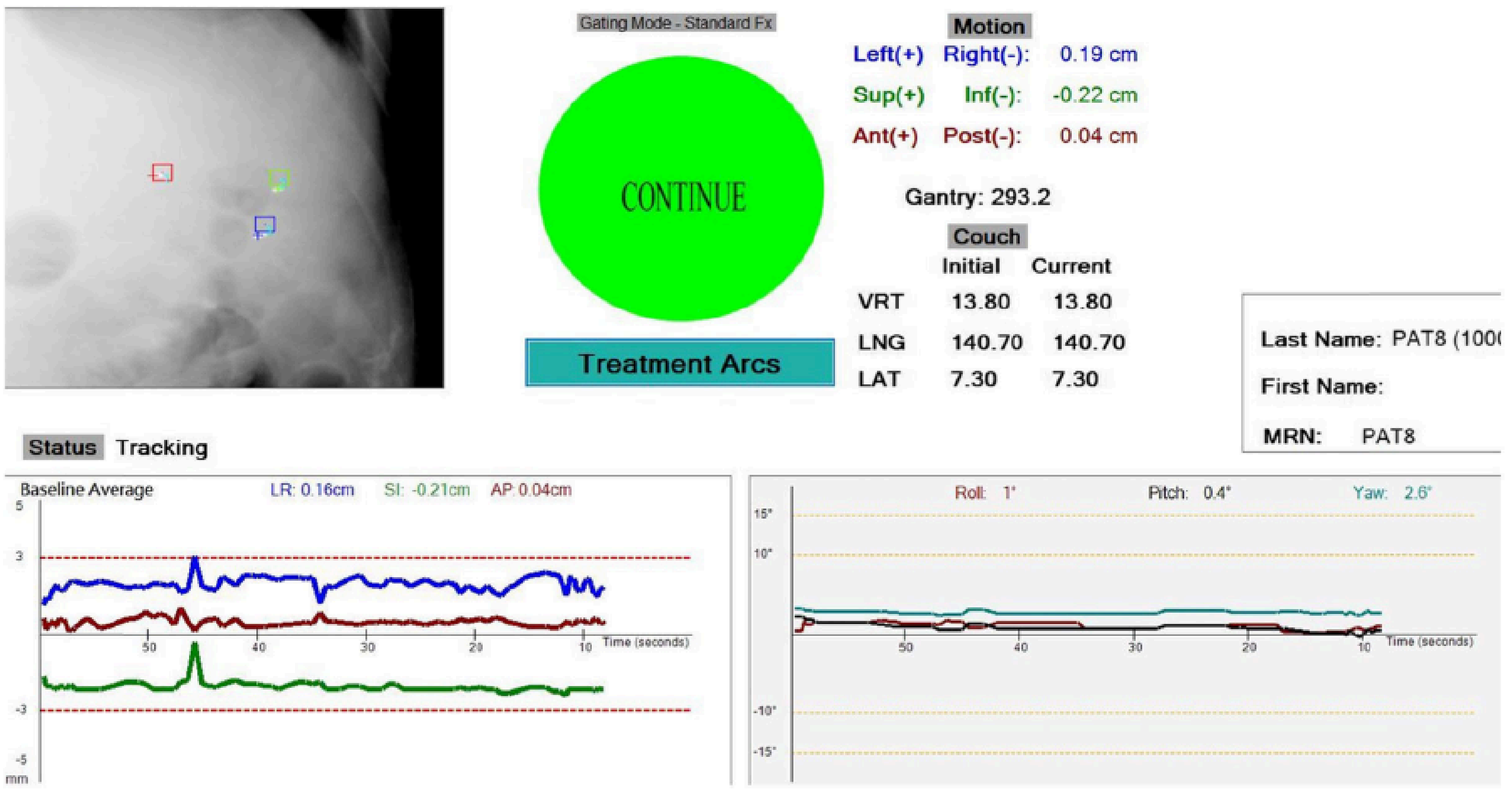


Fig. 1 A screenshot of the KIM user interface for liver SABR to be used in the LARK trial. Live-streamed kilovoltage images show the marker positions (crosses) and the planned positions (boxes). From the kilovoltage images the liver 3D translation and 3D rotation values are displayed. If the target motion exceeds a pre-set threshold from the planned position the operator is warned and then instructed to pause the treatment. The patient position is then shifted to align with the beam and the treatment continues

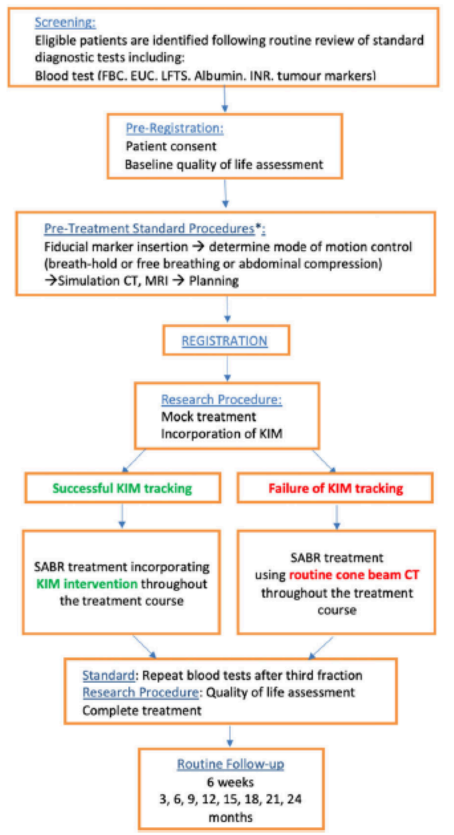
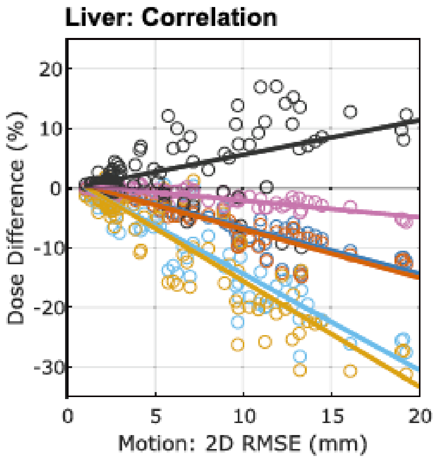
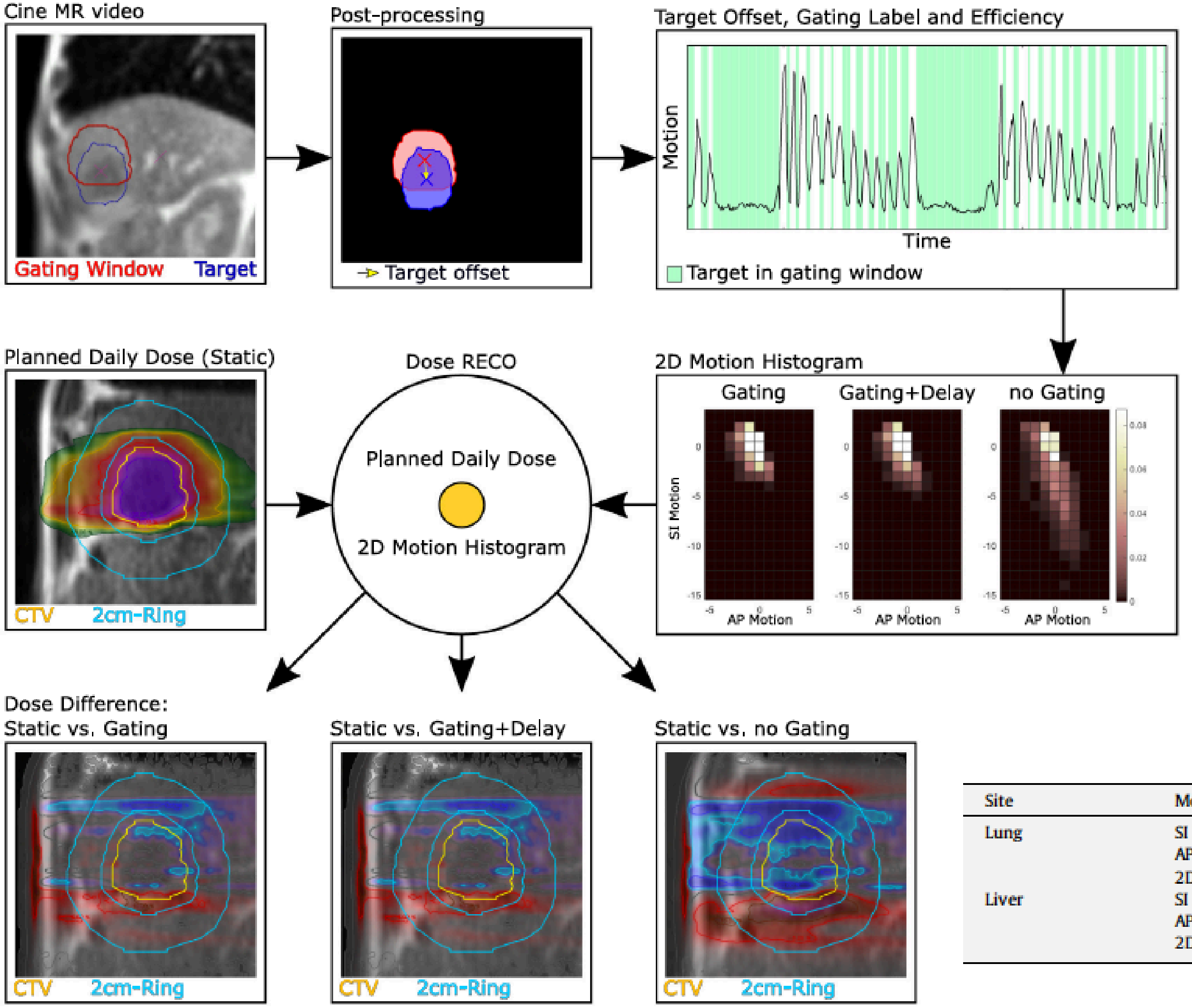


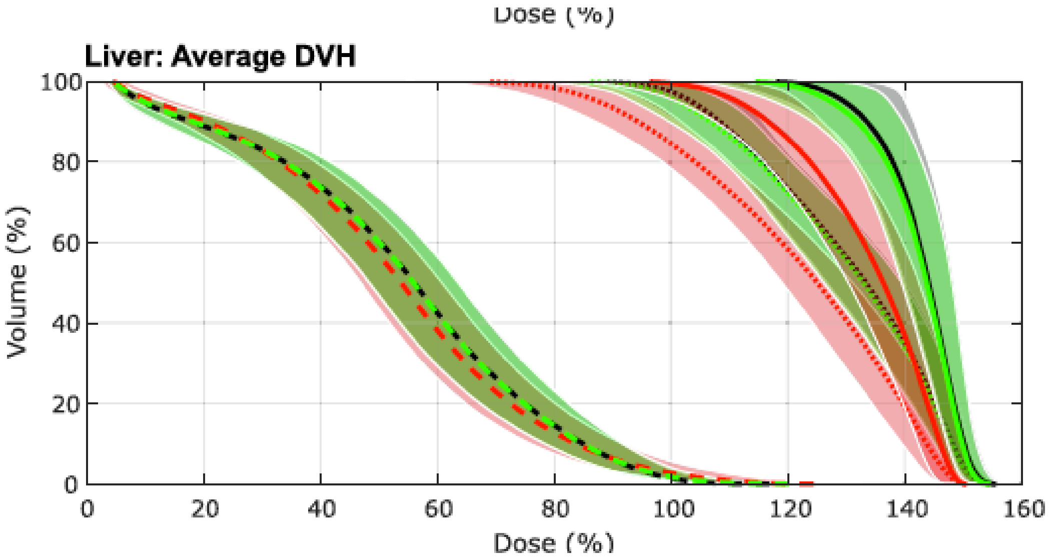
Fig. 2 The LARK study schema

MR-guided beam gating: Residual motion, gating efficiency and dose reconstruction for stereotactic treatments of the liver and lung

Stefanie Ehrbar *, Sarah Braga Käser, Madalyne Chamberlain, Jérôme Krayenbühl, Lotte Wilke, Michael Mayinger, Helena Garcia Schüler, Matthias Guckenberger, Nicolaus Andratschke, Stephanie Tanadini-Lang

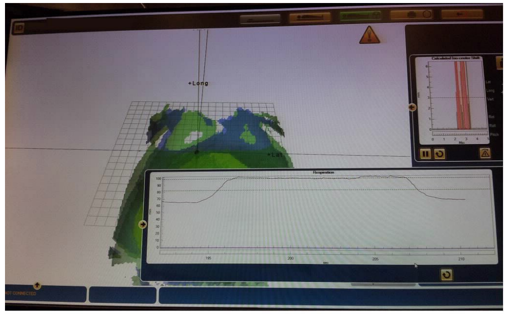




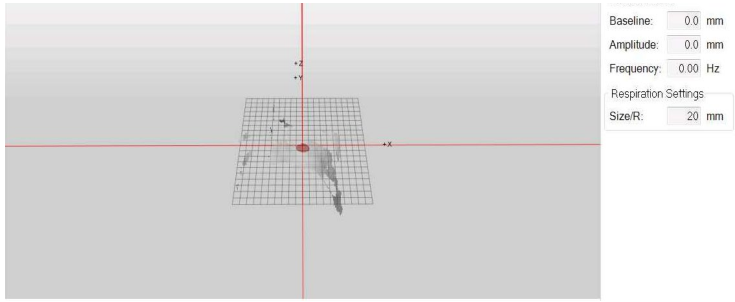


Site	Motion Parameter	No Gating	Gating	Delayed Gating
Lung	SI Range (mm)	14.9 ± 10.1 (1.5, 33.5)	4.9 ± 1.9 (1.5, 10.2)$^{\circ}$	5.4 ± 2.3 (1.5, 11.6)$^{\circ *}$
	AP Range (mm)	8.9 ± 5.4 (0.9, 22.5)	3.9 ± 1.4 (0.9, 7.4)$^{\circ}$	4.0 ± 1.4 (0.9, 7.4)$^{\circ *}$
	2D RMSE (mm)	6.8 ± 3.8 (0.7, 15.7)	2.4 ± 0.7 (0.7, 4.3)$^{\circ}$	2.5 ± 0.8 (0.7, 4.5)$^{\circ *}$
Liver	SI Range (mm)	23.4 ± 10.9 (4.4, 48.7)	5.3 ± 1.0 (2.3, 8.3)$^{\circ}$	5.9 ± 1.3 (2.6, 10.1)$^{\circ *}$
	AP Range (mm)	8.7 ± 3.6 (3.7, 18.1)	3.2 ± 0.8 (1.4, 6.4)$^{\circ}$	3.3 ± 0.8 (1.7, 6.4)$^{\circ *}$
	2D RMSE (mm)	9.7 ± 4.4 (2.8, 20.0)	2.3 ± 0.4 (1.1, 4.2)$^{\circ}$	2.6 ± 0.5 (1.2, 4.4)$^{\circ *}$

SGRT...?




catalyst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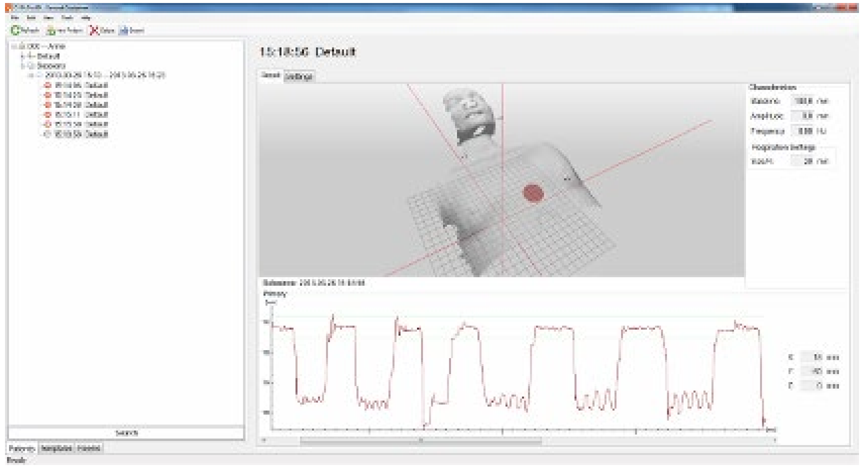
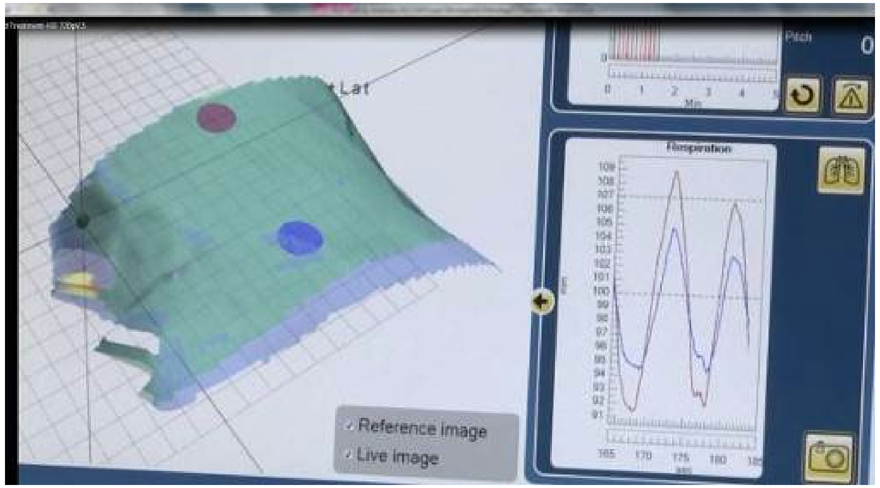
Amplitude: 0.0 mm
Frequency: 0.00 Hz
Respiration Settings
Size/R: 20 mm


Elekta
Versa HD


15:18:56 Default


Lat
Pitch
Respiration
Reference image
Live image

Intrafractional relationship changes between an external breathing signal and fiducial marker positions in pancreatic cancer patients

J Appl Clin Med Phys 2020; 21:3:153–161

Niclas Pettersson[1,2,3] | Oluwaseyi M. Oderinde[1] | James Murphy[1] | Daniel Simpson[1] | Laura I. Cerviño[1,4]

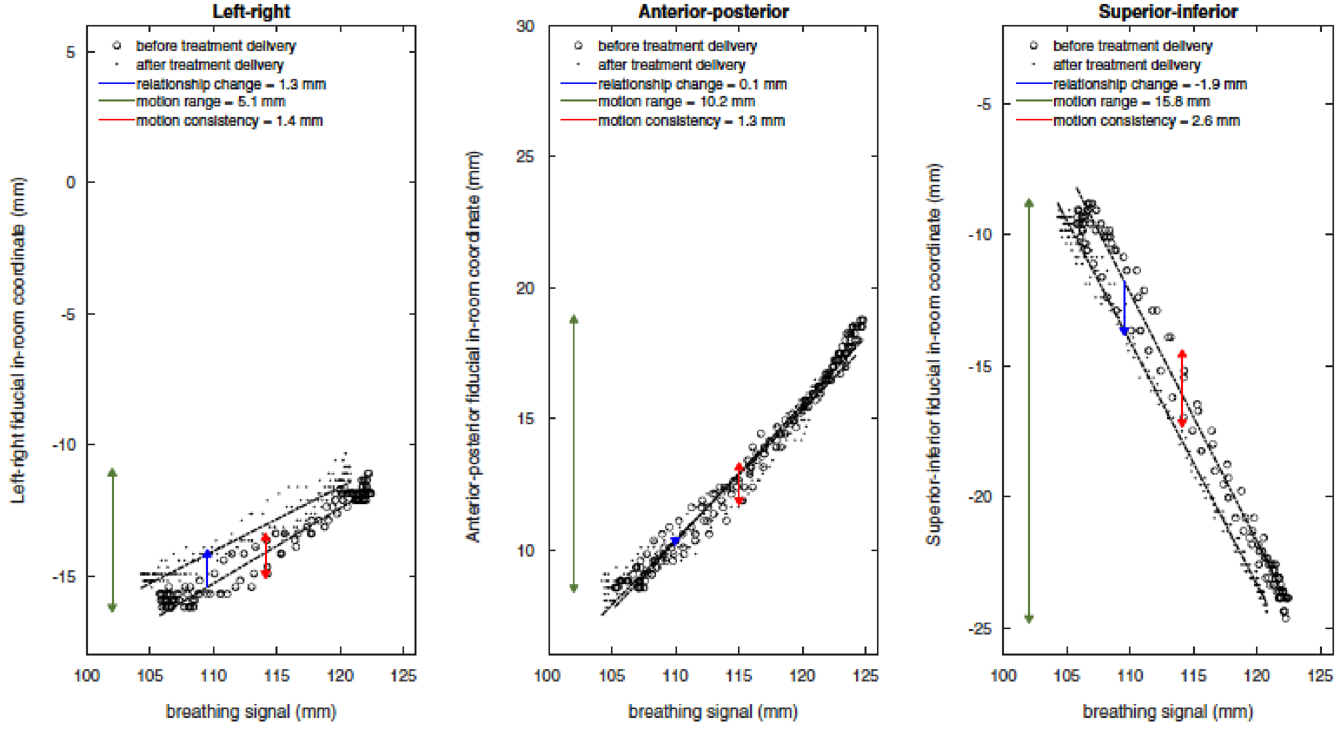


FIG. 1. Illustration of the intrafractional relationship changes at 25% at the common breathing signal range for one fraction (blue arrows). Also shown are the fiducial motion ranges (green lines) and the fiducial motion consistency (red lines). Data are shown for one of the fiducials.

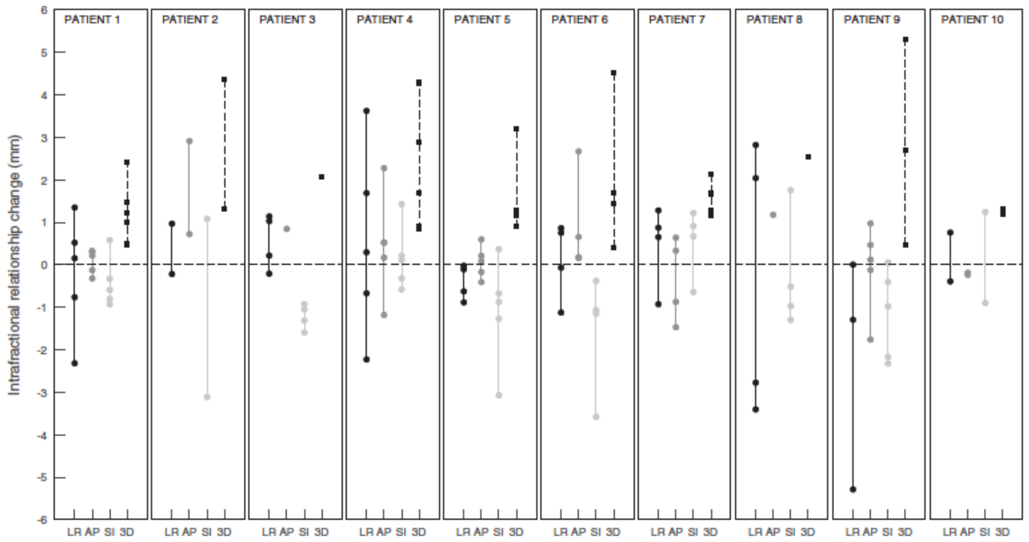


FIG. 2. Intrafractional relationship change between the breathing signal and fiducial in-room coordinates (average value for all implanted fiducials). For patients with more than one fiducial marker, the standard deviation of the relationship change for all the fiducials is typically less than 0.5 mm. LR, left–right; AP, anterior–posterior; SI, superior–inferior.

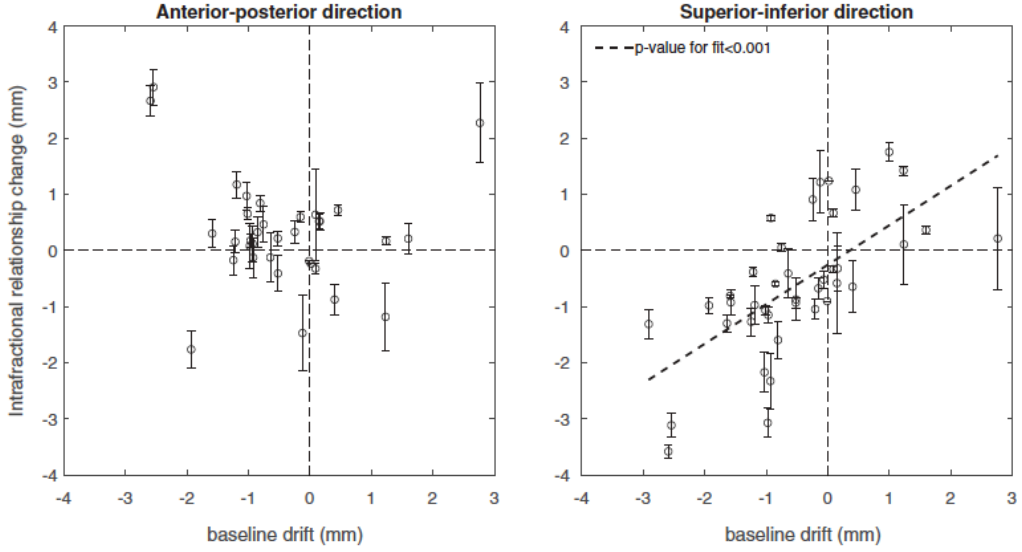


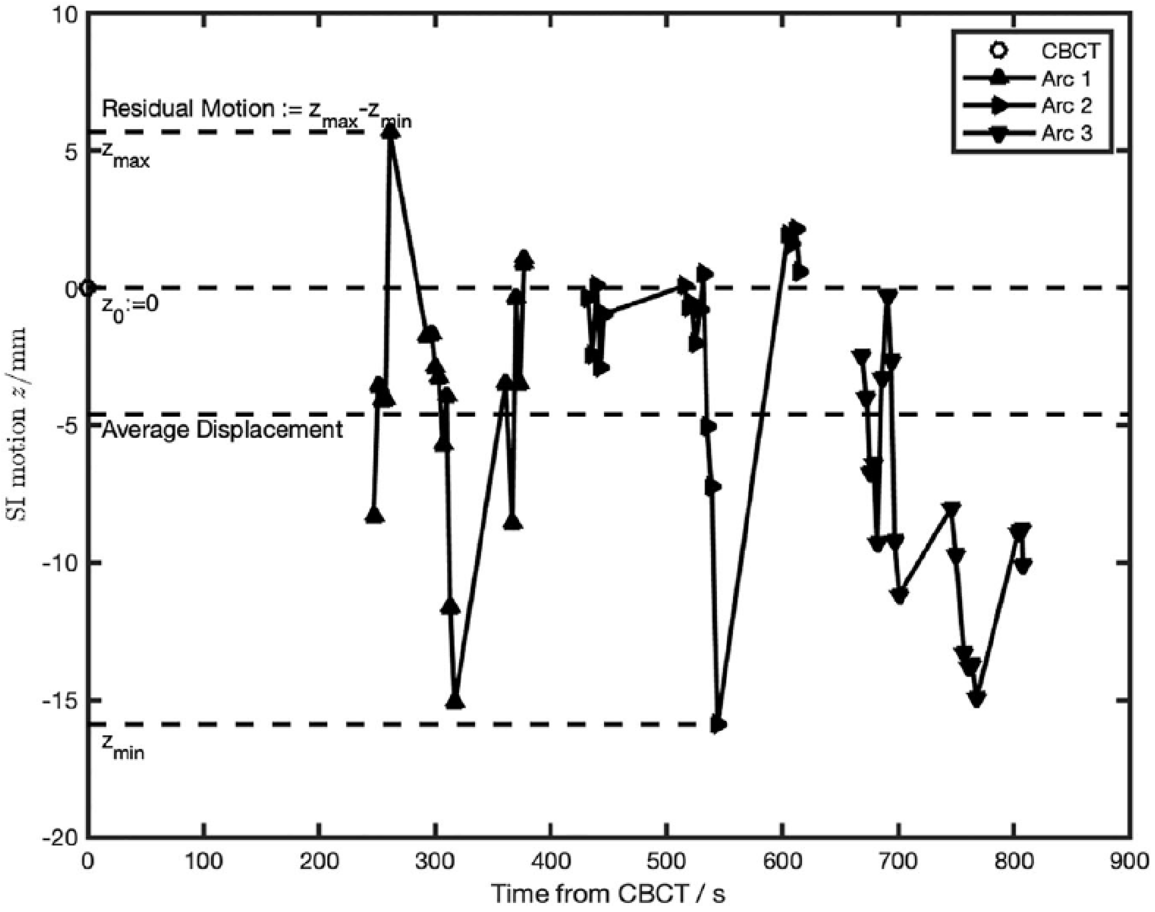
FIG. 5. Intrafractional relationship changes versus the baseline drift. Left-hand side: anterior–posterior direction. Right-hand side: superior–inferior direction.

External signal vs. fiducial changed 2mm within 8 min

Intrafractional accuracy and efficiency of a surface imaging system for deep inspiration breath hold during ablative gastrointestinal cancer treatment

J Appl Clin Med Phys. 2022;e13740.
https://doi.org/10.1002/acm2.13740

Chuan Zeng[1] | Wei Lu[1] | Marsha Reyngold[2] | John J. Cuaron[2] | Xiang Li[1] | Laura Cerviño[1] | Tianfang Li[1]

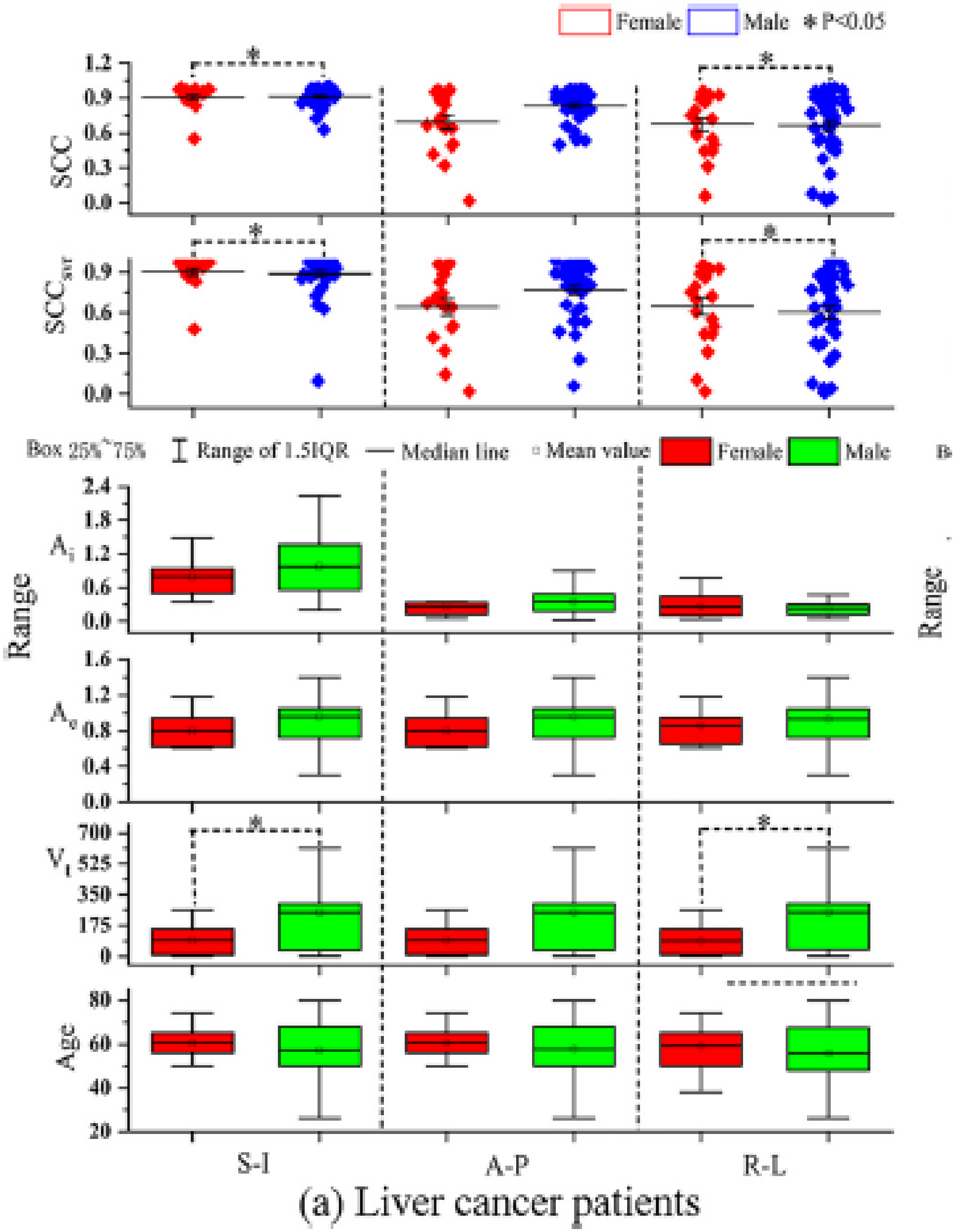


- ITV movement sign. different from external surrogate movement
- SGRT as solo is discouraged
- Real-time radiographic target location verification is essential

Correlation of Optical Surface Respiratory Motion Signal and Internal Lung and Liver Tumor Motion: A Retrospective Single-Center Observational Study

Technology in Cancer Research & Treatment
Volume 21: 1-11

Guangyu Wang, MM[1,*], Xinyu Song, MM[1,*], Guangjun Li, MS[1], Lian Duan, BE[1], Zhibin Li, MM[2], Guyu Dai, MM[1], Long Bai, MS[1], Qing Xiao, MM[1], Xiangbin Zhang, MM[1], Ying Song, MS[1], and Sen Bai, MS[1]

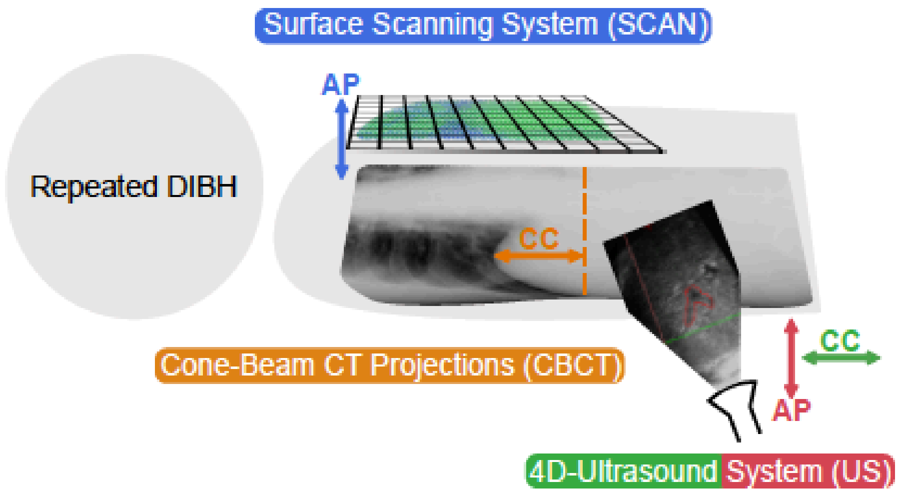


- External and internal motion correlate in SI direction
- Correlation differs by a high degree for various patients
- Individual, patient-based assessment of correlation needed

Intrafractional IGRT – Ultrasound-based monitoring vs. SGRT vs. DD detection in CBCT projections…

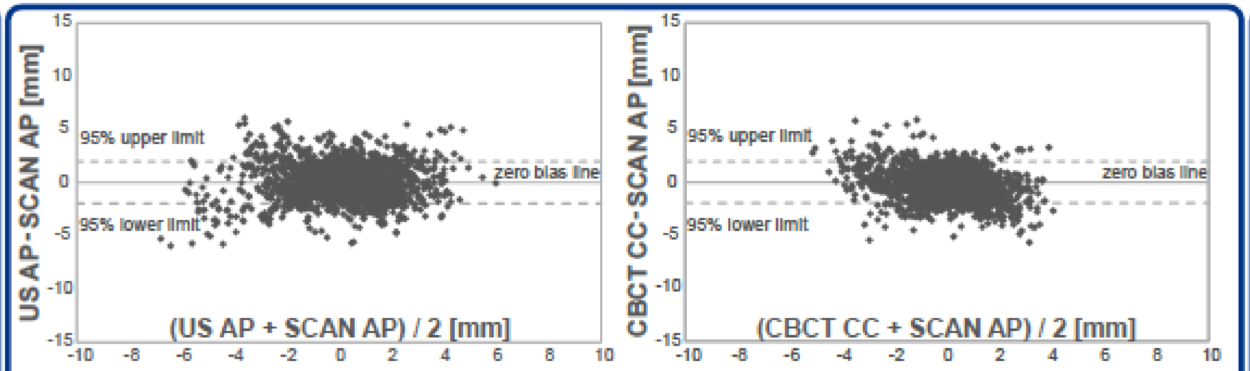
Is surface tracking a sufficient surrogate for monitoring spirometry induced breath-hold accuracy during upper abdominal SBRT? A comparison with 4D ultrasound-based tracking and diaphram position in Cone-Beam CT

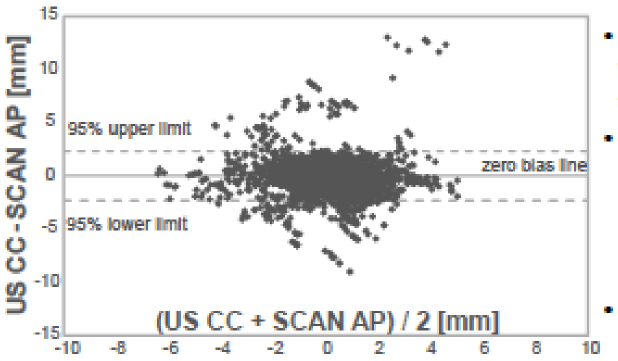
Patients & Setup



Patients with upper abdominal SBRT (n=12)

Results (Agreement analysis, Bland-Altman plots)





- numerical values of detected residual motion were larger for surface measurements (SCAN) than for internal measurements (US/ CBCT)
- lowest agreement US CC vs. SCAN AP
  - **Wilcoxon's test:** p 0.04 ($p < 0.05$)
  - **Maloney & Rastogi's test:** sign. difference
  - **Pearson's Correlation Coefficient:** 0.44
  - **Interclass Correlation Coefficient:** 0.42
- most agreement US AP vs. SCAN AP

Conclusions

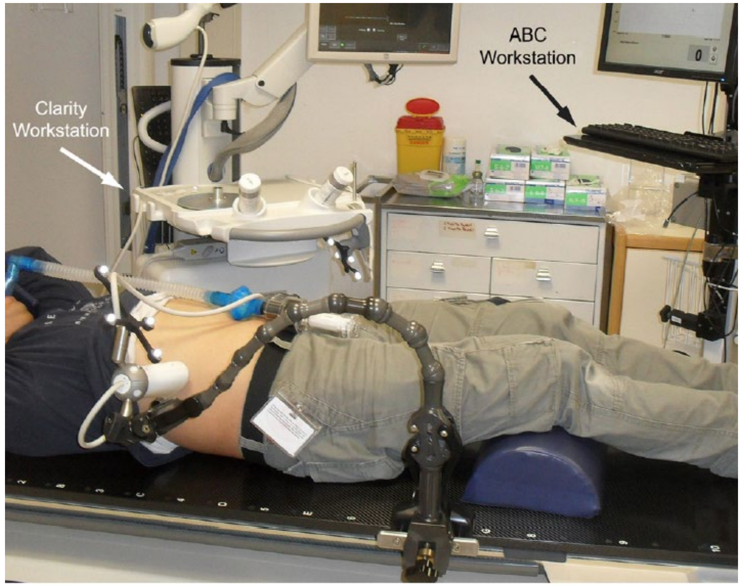
In most cases, both ultra-sound and surface moni-toring detected larger motion and would be su-fiicient to trigger beam interruption.

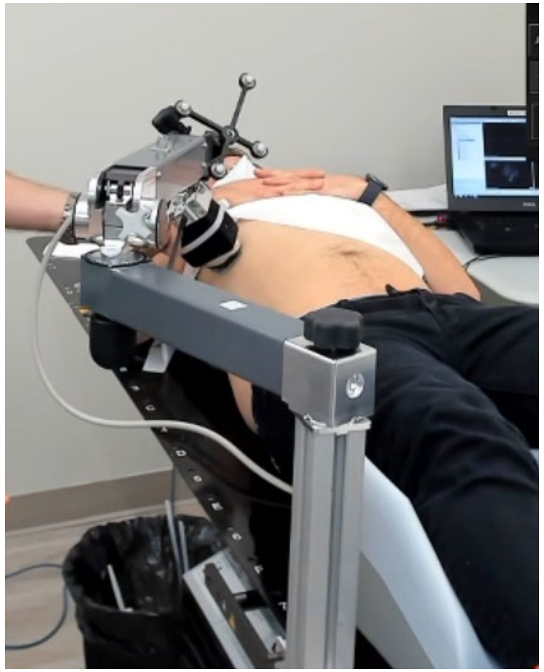
The highest accuracy in detecting residual internal craniocaudal motion was observed for soft-tissue monitoring.

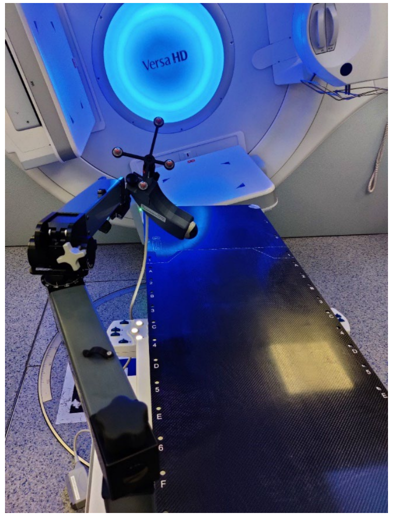
Patient-specific residual errors may require indivi-dualised PTV-margins.

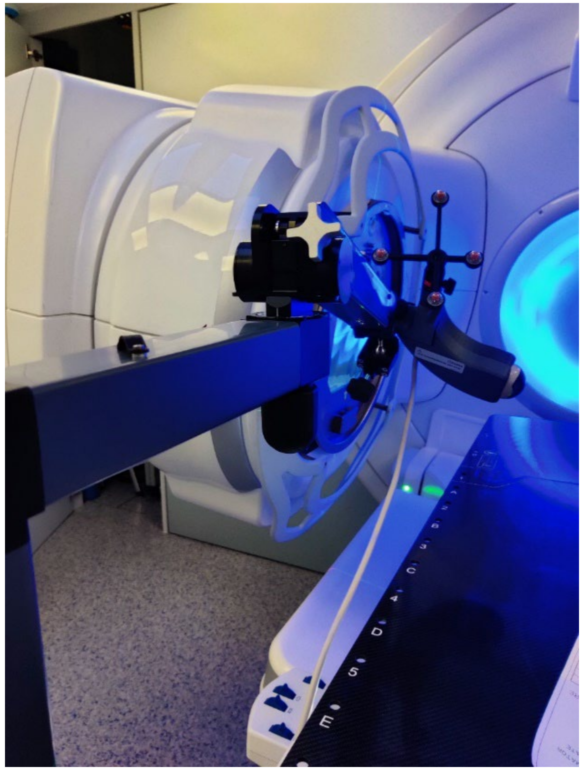
Kaestner et al., under Review/minor revisions Phys Med

US: not commercially available for abdominal RT
Hardware/software development issues…









Eckl/Boda-Heggemann, unpublished data

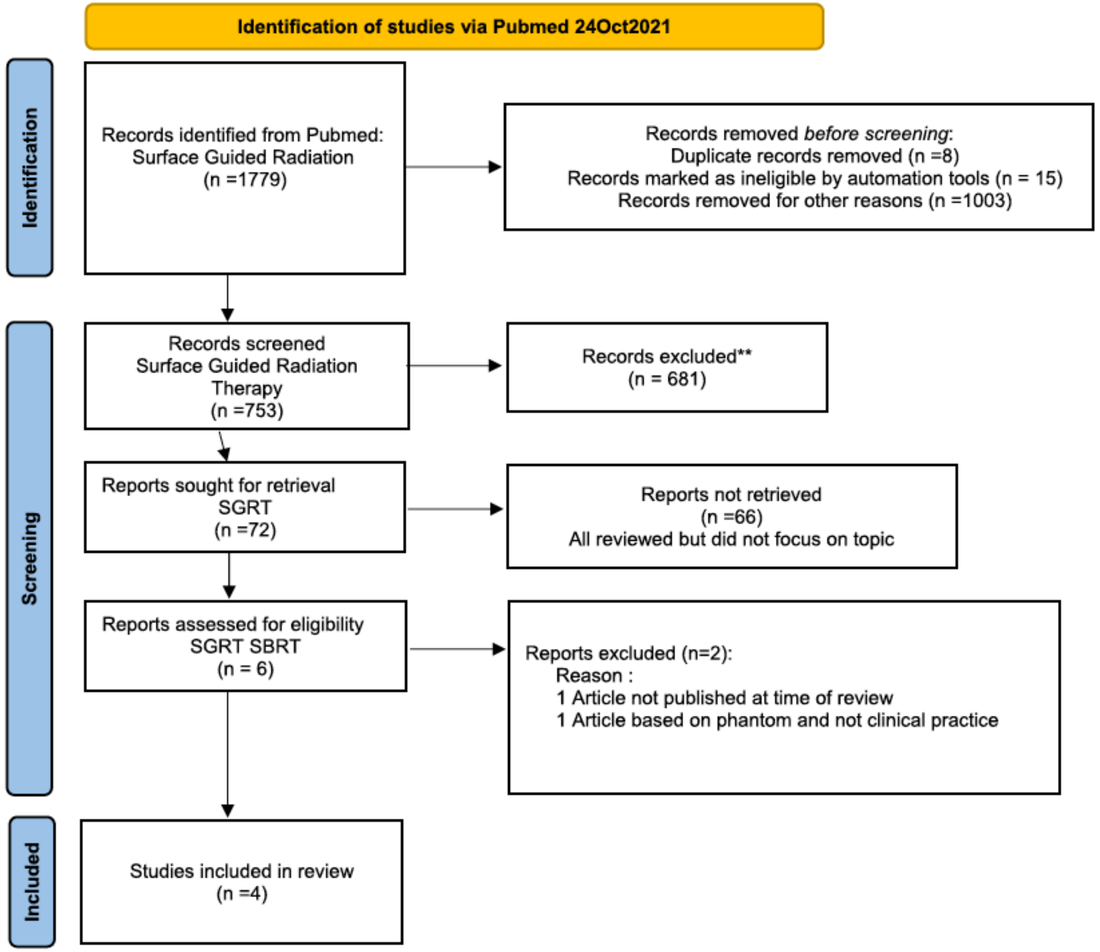
Elekta

Intrafractional IGRT – SGRT?

A review of surface guidance in extracranial stereotactic body radiotherapy (SBRT/SABR) for set-up and intra-fraction motion management

Gavin Lawler

Technical Innovations & Patient Support in Radiation Oncology 21 (2022) 23–26



SGRT:
- for patient setup
- intrafraction motion management
- only in presence of rigorous IGRT protocols!
- secondary after CBCT
- Verification of couch shifts
- indication for repeat CBCT
- Distinguishing between different respiratory patterns
- (abdominal vs. thoracic breathing)
- Synergystic approach in combination with e.g. X-ray imaging/US

AAPM task group report 302: Surface-guided radiotherapy

Hania A. Al-Hallaq[1] | Laura Cerviño[2] | Alonso N. Gutierrez[3] | Amanda Havnen-Smith[4] | Susan A. Higgins[5] | Malin Kügele[6,7] | Laura Padilla[8] | Todd Pawlicki[8] | Nicholas Remmes[9] | Koren Smith[10] | Xiaoli Tang[11] | Wolfgang A. Tomé[12]

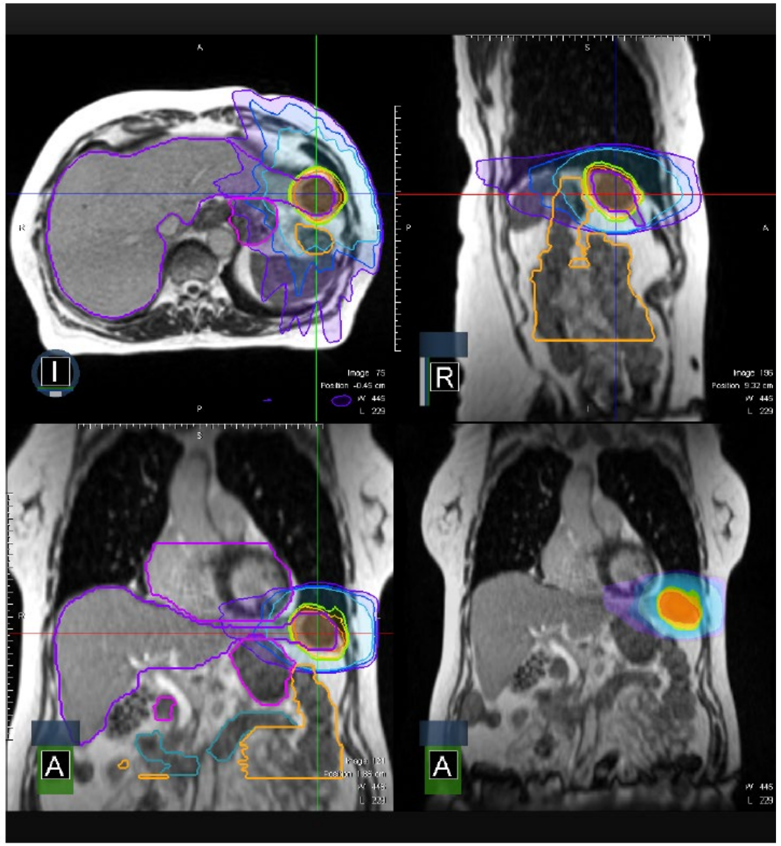
Med Phys. 2022;49:e82–e112.

MR-Linac mit atemgesteuertem Gating

Liver Seg II mit Kontakt zu Darm

LMU München

04/2020: 40Gy in 5Fx (80% isodose)



Patienten Positionierung → 3D MRT → Bild Registrierung → Konturierung → Dose prediction/ Neuer Plan → Online Plan QA → Erneutes 2D MRT → Bestrahlung

PD Dr. Stefanie Corradini, LMU

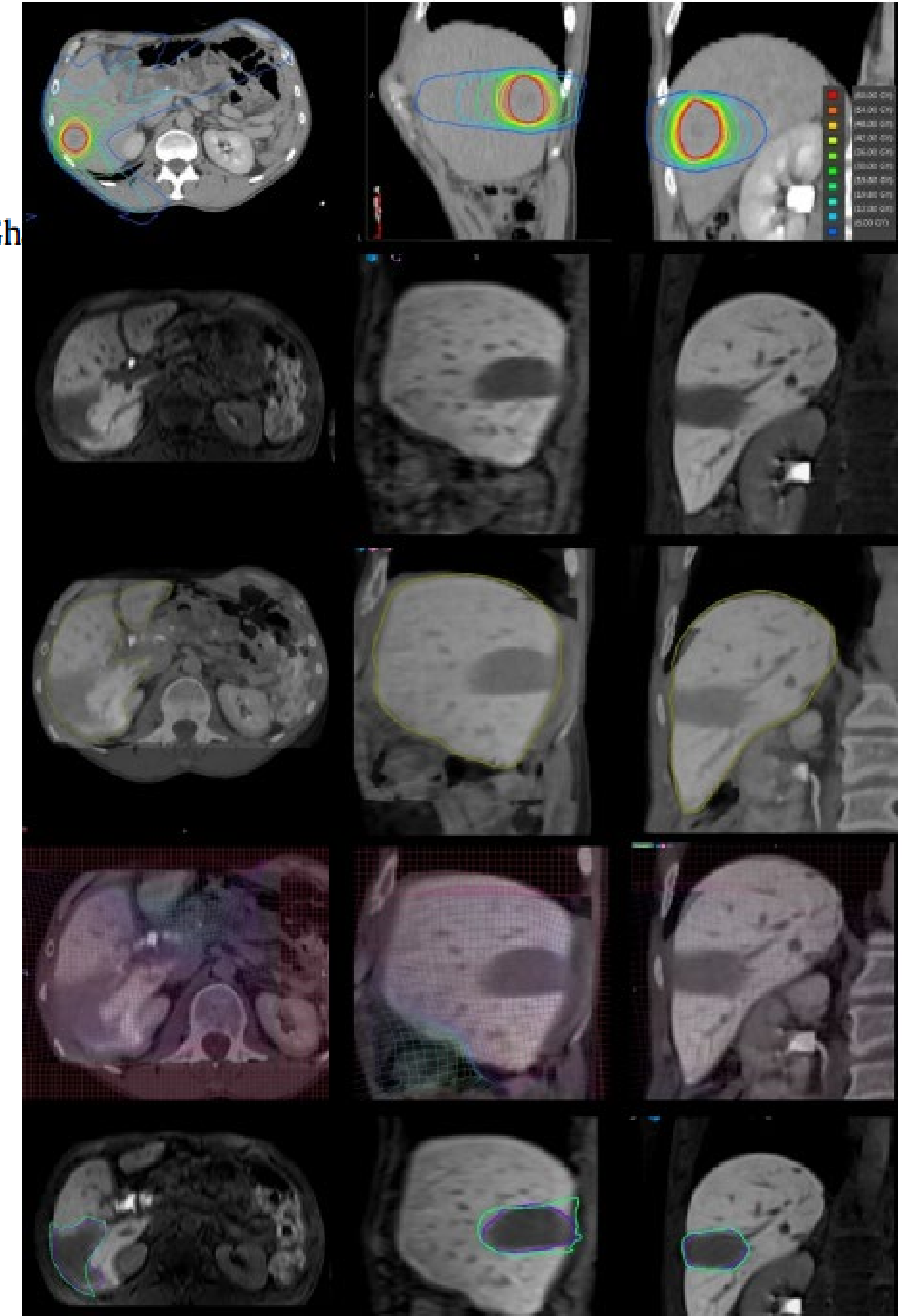
Online adaptive workflow

In-vivo treatment accuracy analysis of active motion-compensated liver SBRT through registration of plan dose to post-therapeutic MRI-morphologic alterations

Judit Boda-Heggemann [a,*], Anika Jahnke [a,*], Mark K.H. Chan [b], Floris Ernst [c], Ardekani Leila Gh
Ulrike Attenberger [d], Peter Hunold [e], Jost Philipp Schäfer [f], Stefan Wurster [g,h], Dirk Rades [i],
Guido Hildebrandt [j], Frank Lohr [k], Jürgen Dunst [b], Frederik Wenz [a], Oliver Blanck [b,g]

Radiotherapy and Oncology 134 (2019) 158–165

- in-vivo accuracy assessment isodose lines versus post-SBRT MR alterations
- mean surface distance 2mm
- median CI 0.8
- both DIBH/robotic tracking: median deviations <5mm
- patient-specific safety margings needed for rare cases of larger errors



Geometric and dosimetric comparison of four intrafraction motion adaptation strategies for stereotactic liver radiotherapy

Phys. Med. Biol. **63** (2018) 145010 (12pp)

Saber Nankali[1,2], Esben S Worm[3], Rune Hansen[3], Britta Weber[1,4], Morten Høyer[4,5], Alireza Zirak[6] and Per Rugaard Poulsen[1,5]

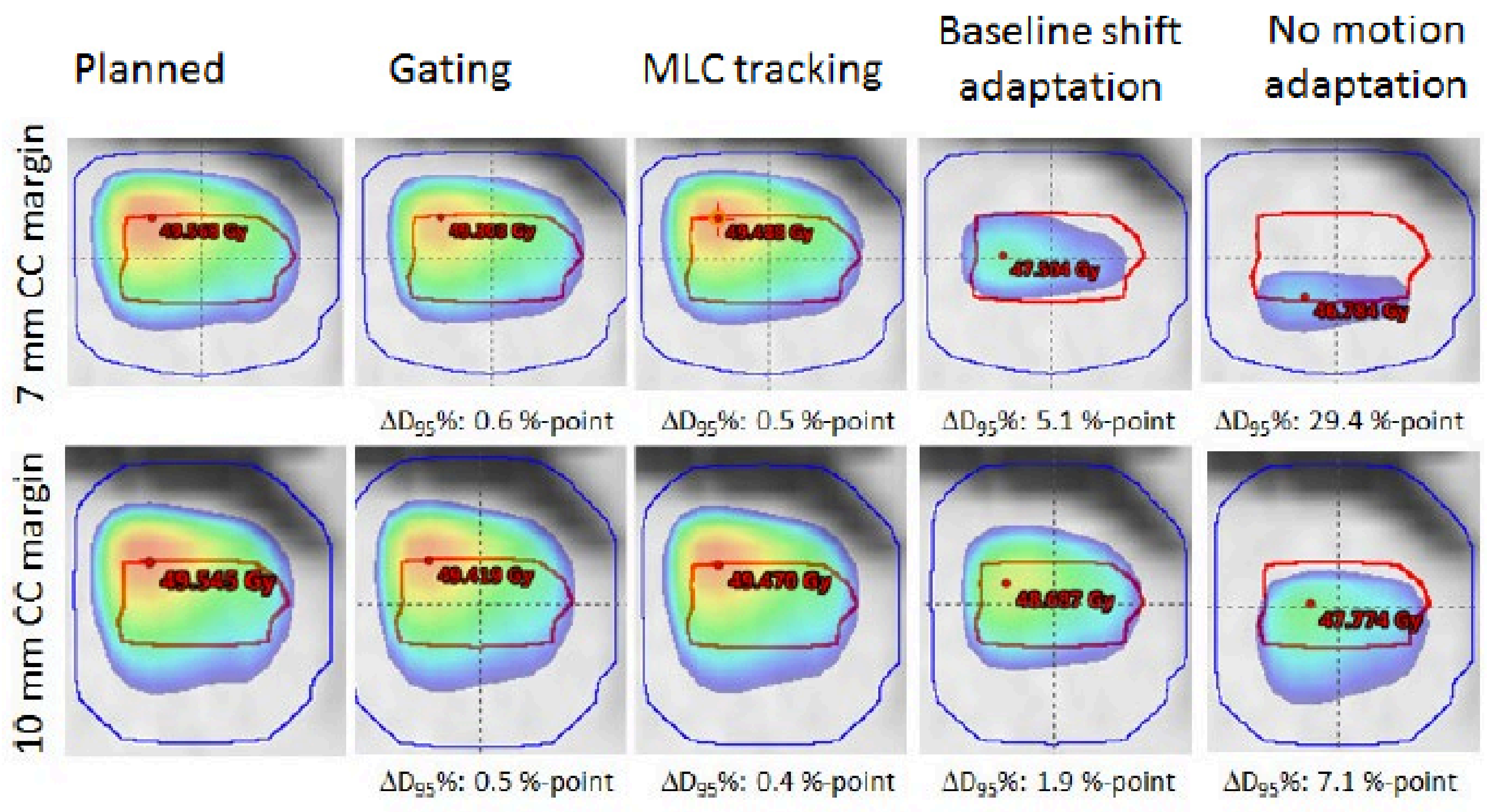


Figure 3. Planned dose distribution in the coronal plane in the center of the CTV (red contour) and PTV (blue), and reconstructed dose distributions for all motion adaptation strategies accumulated over all three fractions for Patients 1 and 11. Dose levels ⩾95% are shown. The numbers specify the reduction in CTV D_{95} caused by intrafraction motion.

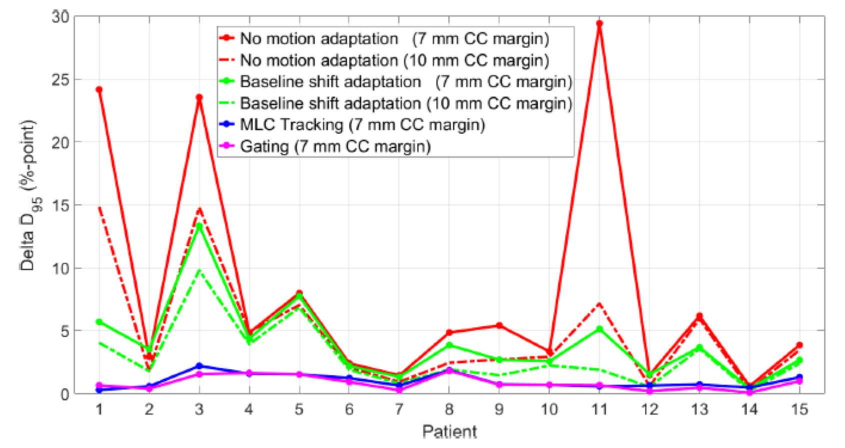


Figure 4. Mean reduction in delivered CTV D_{95} dose relative to the planned dose per patient for all motion adaptation strategies.

- 4 MM strategies compared
- gating and tracking most effective

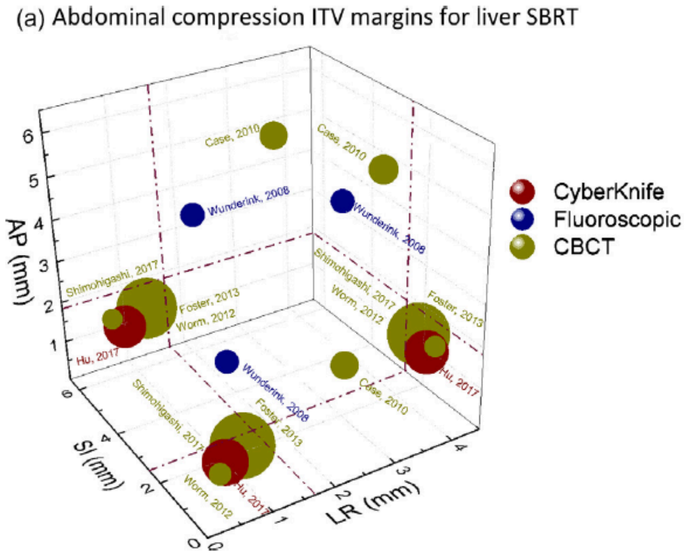
Radiotherapy and Oncology 166 (2022) 195–202

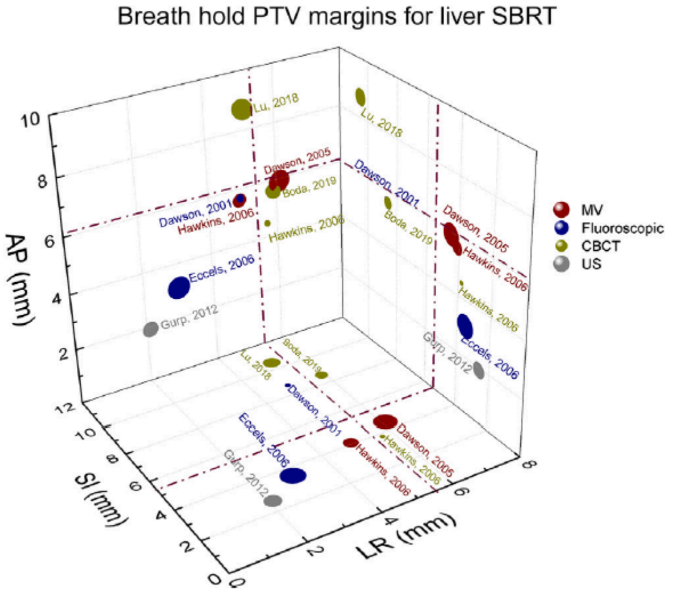
A systematic review and meta-analysis of liver tumor position variability during SBRT using various motion management and IGRT strategies

Manju Sharma [a,*], Tomi F. Nano [a], Meghana Akkati [b], Michael T. Milano [c], Olivier Morin [a], Mary Feng [a]

Table 1
A summary of the studies included in the meta-analysis showing the IGRT methods, inter- and intra-fraction liver position variability (weighted mean and CI_{95}) and margins computed using inter- and intra-fraction position variability (weighted mean and standard deviation) during SBRT with free-breathing (FB), abdominal compression (AC) and breath-hold (BH). Additional detail for each study and motion management technique is shown in supplemental Tables A1–A3.

		Free Breathing (FB)		Abdominal Compression (AC)		Breath-Hold (BH)	
IGRT Methods ($n_{studies}$, $n_{patients}$)		CyberKnife (5, 226) kV fluoroscopy (6, 72) 4D-CBCT (4, 67) Calypso (2, 30) US (1, 6)		4D-CBCT (2, 24) CBCT (3, 50) Contrast CT (1, 20) MVCT (1, 27) kV fluoroscopy (2, 24)		MV portal (2, 33) kV fluoroscopy (2, 27) CBCT (2, 28) US/CBCT (1, 14) US (1, 10)	
		Motion (CI_{95})	Margin	Motion (CI_{95})	Margin (±std)	Motion (CI_{95})	Margin (±std)
Intra (mm)	SI	9.7 (9.3–10.1)	13 ± 4.9	1.8 (1.6–2.0)	2.6 ± 1.2	2.4 (2.1–2.7)	5.6 ± 2.9
	LR	5.4 (5.3–5.6)	7.3 ± 7.9	0.7 (0.6–0.8)	1.7 ± 1.5	1.8 (1.3–2.2)	5.5 ± 1.7
	AP	4.2 (4.0–4.4)	6.3 ± 7.6	0.9 (0.8–1.0)	1.9 ± 1.7	1.4 (1.2–1.7)	6.1 ± 2.1
Inter (mm)	SI	4.7 (4.3–5.1)	5.7 ± 1.7	2.6 (2.3–3.0)	5.2 ± 2.9		
	LR	1.4 (1.1–1.6)	3.6 ± 2.7	1.9 (1.7–2.1)	4.0 ± 2.2		
	AP	2.8 (2.5–3.1)	4.8 ± 2.1	2.9 (2.5–3.2)	5.8 ± 2.7		





Margin recommendation based on weighted van Herk margins

Image-guided Radiotherapy to Manage Respiratory Motion: Lung and Liver

Clinical Oncology 32 (2020) 792–804

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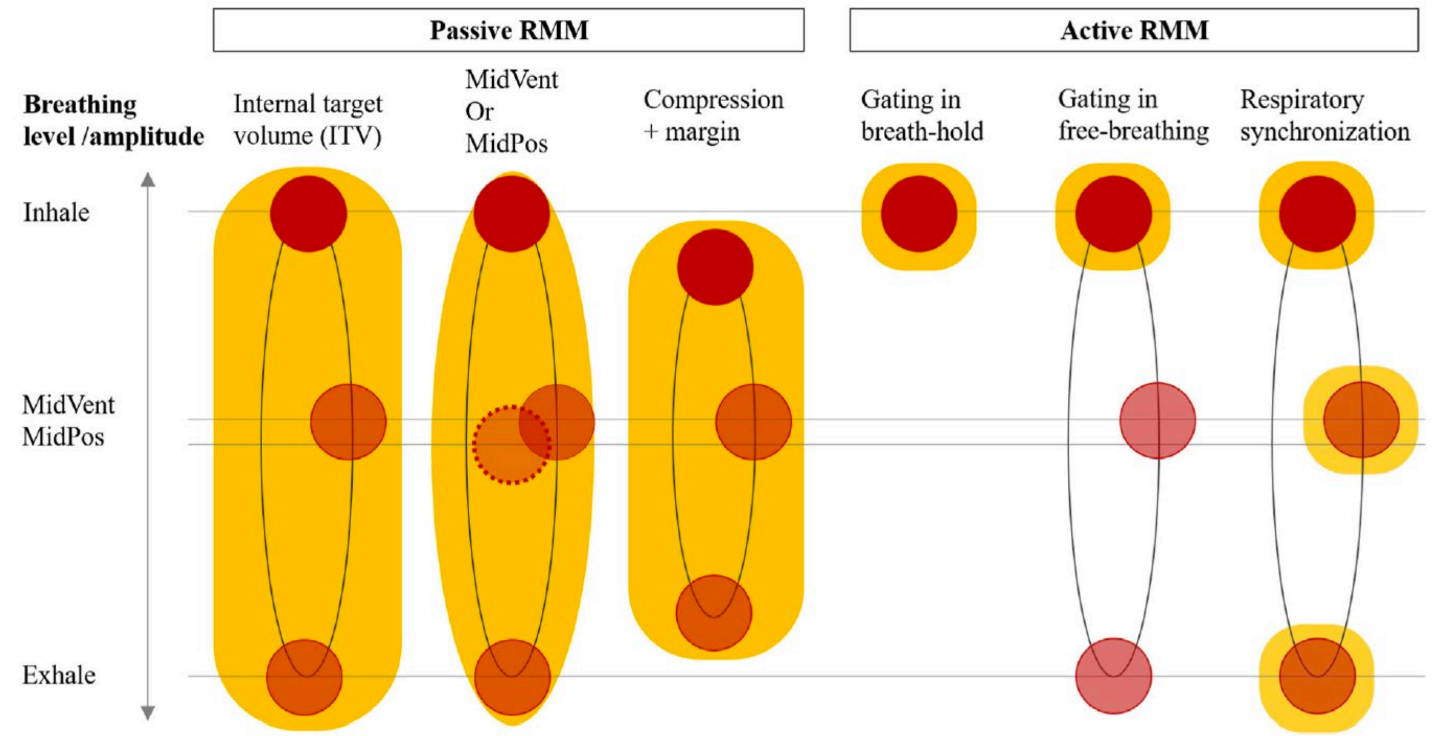

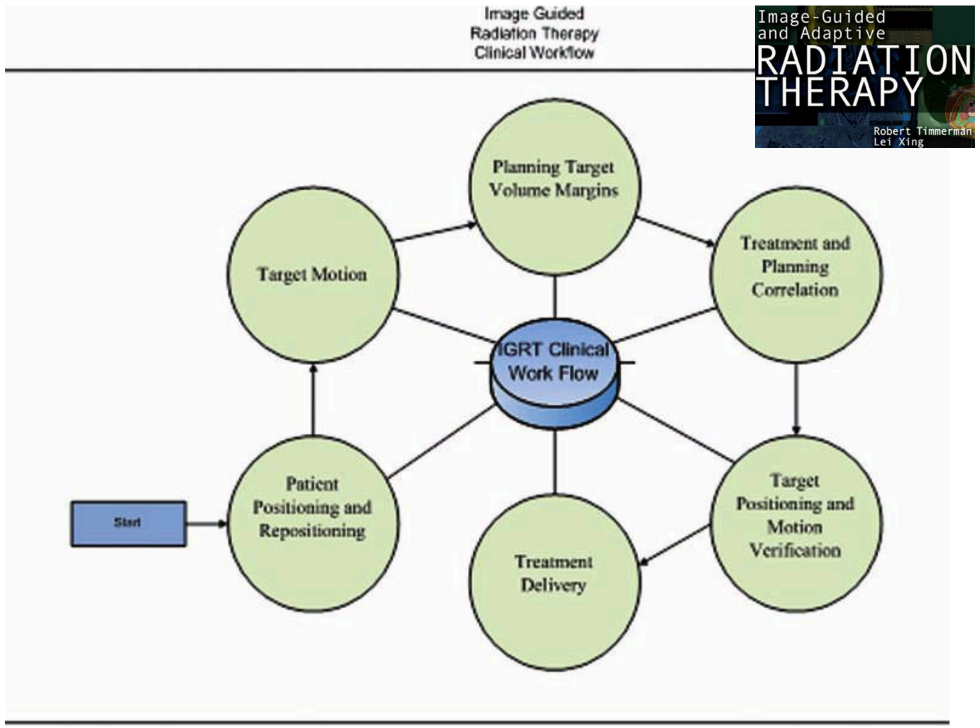

(b) **GI Decision Table**

Does the Patient Have Fiducials or Surgical Clips?[1]	Able to Evaluate Full Range of Motion (0% - 50% Phases)?	Able to Evaluate Motion Around Expiration (30% - 70% Phases) Reliably?	What is the Measured Motion?	Gating Decision	Recommended PTV Margin	Gating Window Selection	Fluoro at TX?	Gating Structure for Fluoro
Y	Y		≤5 mm	Gate100	Non-Pancreas: 5mm Isotropic Pancreas: 2mm Isotropic[2]	Nomal	Y	Fiducials/ Surgical Clips[1]
			≥5 mm	Gate3070				
	N	Y	≤5 mm	Gate3070				
			>5 mm	Gate4060				
		N	Discuss with physicist on Lung/GI Teams and recommend to attending physician[3]					
N	Y		Any	Gate100	Non-Pancreas: 5mm radial, 7mm sup/inf Pancreas: 5mm Isotropic	Conservative	N	
	N	Y	Discuss with physicist on Lung/GI Teams and recommend to attending physician[3]					
		N						

[1]Stents and Calcificiations do NOT count as fiducials. Surgical clips must be very near tumor. Lipiodol may be used.
[2]Pancreas cases are always palliative, thus OAR sparing more critical than risk for marginal miss
[3]Optional recommendations: Re-4DCT, Gate 100 with increased PTV margins

A standardized workflow for respiratory-gated motion management decision-making

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